Populus "androscoggin": SOME WOOD CHARACTERISTICS AND DRYING OPTIONS

A REPORT
SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE
OF
MASTER OF FORESTRY SCIENCE
IN THE
SCHOOL OF FORESTRY
UNIVERSITY OF CANTERBURY

BY
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UNIVERSITY OF CANTERBURY
1990

ABSTRACT

This study explored the wood properties of Populus "androscoggin" (*Populus trichocarpa* X *Populus maximowiczii*) grown in a river bed plantation near Timaru. The objectives of this study were :

(1) to determine some general characteristics of the tree viz. diameter over bark, diameter under bark, bark thickness, eccentricity and the diameter of heartwood.

(2) to improve the quality of sawn timber by drying the timber so as to reduce the effect of tension wood and growth stresses in poplar.

Thirty trees were selected for this study : 15 leaning trees and 15 straight trees. The study was conducted in three parts:

(1) disk analysis to determine the general wood characteristics
(2) determining drying characteristics based on the quality of dried flitches
(3) determining the quality of dried boards after remanufacture.

In the first part of the study sample disks were removed at three heights from each tree to examine the variation within the tree. The mean number of annual rings at the butt of the tree was 16 in the case of leaning trees and 17 in straight trees. The growth rate (ring width (mm)) of the leaning trees was not statistically different from the growth rate of straight trees. It was found that bark thickness was positively correlated with the diameter over bark. Bark thickness also has a positive relationship with heartwood diameter and negative relationship with height.

The average green moisture content of individual trees ranged from 109 % to 146 %. The green moisture content decreased from the butt to the top of the tree. A positive relationship was found between the green moisture content and the proportion of heartwood (heartwood diameter/the diameter under bark).

The green density followed a similar trend to that of the distribution of green moisture content , and decreased from the butt to the top of the tree.

Basic density values in the 30 trees were,

- butt: 320 to 380 Kg/m^3
- middle: 340 to 410 Kg/m^3
- top: 360 to 430 Kg/m^3.

It was found that the distribution of basic density based on the "direction" in the tree was different in straight trees and leaning trees. In leaning trees the basic density of the "side" was statistically different from that of the "opposite" direction, whereas in straight trees there were no differences between directions. It was also found that the basic density of leaning trees was higher than the basic density of straight trees.

Within the stem, basic density was negatively correlated with the heartwood proportion, negatively correlated with the average ring width, and positively correlated with its eccentricity.

In the second part of the study, the logs from the butt and the top were converted into flitches. The flitches were then dried using six drying schedules. One of the drying options (dehumidifying) was not completed due to time limitations.

Air drying schedule which was begun on 24 April 1989 finished on 30 March 1990 (11 months), with the average moisture content ranging from 17.2 % to 25.8 %. The other four categories of drying options were low temperature drying (40°C), conventional drying I (60°C), conventional drying II (80°C) and high temperature drying (115°C). When dried at low temperature the boards showed minor defects (warping), conventional drying I and conventional drying II decreased the drying time but the effect on defects was not significant. High temperature drying decreased the drying time and also decreased the amount on warp of the dried flitches.

More boards were rejected from leaning trees than from straight trees. More boards were rejected from bottom logs than from top logs.

Volumetric shrinkage was not affected by the type of tree nor the location of the board within the tree. On the other hand drying methods (temperature) had an effect on volumetric shrinkage.

Below 100°C, it was noted that the volumetric shrinkage was positively correlated with temperature, whereas at high temperatures (> 100°C) the opposite was true. This result suggested that the allowance before sawing processes should be made in accordance with the drying methods. The higher the temperature (below 100°C) the higher the allowance.

The rejection rate showed a positive relationship with the volumetric shrinkage.

In the third part of the study, 5 samples from each treatment were selected then remanufactured and the distortion measured. The result after remanufacture was different from that obtained in the second part of the study. The high temperature drying showed a high amount of bowing in remanufactured boards. This indicated that casehardening was present in these boards, and suggested that more reconditioning was needed for this schedule (up to 10 hours instead of 6 hours).

Colour was darkened and there was loss of brightness at higher temperatures. The high temperature drying also produce a "caramel" like odour. This made the boards unsuitable for asparagus containers.

Wetwood may be present in the boards used in this study, since the final moisture content varied greatly between and within the boards. Further research of this abnormal wood is needed to clarify this problem.

This study also suggested that the drying methods should consider the requirement of the final product. Timber intended for manufacture of asparagus containers was suitably processed by conventional drying I or conventional drying II, whereas for other end uses (where the odour and colour were not primarily important) high temperature drying was found to be suitable used in conjunction with an increased reconditioning schedule.

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ACKNOWLEDGEMENTS

First of all I would like to express my very grateful thanks and appreciation to my supervisor Dr. J.C.F. Walker for his invaluable guidance and assistance from the inception to the completion of this study. I would like to extend my special thanks to Mr. P. F. Fuller for his helpful and technical assistance during conducting the experiment and writing the report.

I also wish to thank D.J. Stringer M.For.Sc. and South Canterbury Catchment Boards for providing the materials for this experiment.

I would also like to thank Mr. D. Clark for his help in introducing me to the computer programmes I used for the analysis of the data.

A grateful acknowledgement is made to both the New Zealand Government through the Ministry of External Relations and Trade and the Indonesian Government through the Ministry of Forestry for providing the opportunity and funds for my study at the School of Forestry, University of Canterbury, New Zealand.

Finally, a special acknowledgement is made to my wife Ella and my son Gilang for their uninterrupted love and patience in supporting my study and career in New Zealand become possible.

I. INTRODUCTION

Populus "androscoggin" was one of several populus hybrids planted by South Canterbury Catchment Boards near Timaru. The purpose of the plantation was to protect the land from the adverse effects of erosion and floods. Today this plantation is nearing maturity and ready to be harvested. The returns from the sale of wood will be used to reduce the cost of managing this river bed. Accordingly a high grade of timber product was needed to enhance the financial return.

The possibility exists of using poplar in a variety of products including pulp and paper, particle board, fibre board, plywood and lumber. Neilson (1975) listed some secondary products from poplar lumber:

- furniture parts and furniture
- furniture frames
- unpainted furniture
- mill work
- shelving
- toys
- wooden heels
- containers
- picture frames etc.

Although poplar is reported to be adequate for many uses, it is still considered inferior compared to other species, since poplar is difficult to process especially in drying. The problems in drying are related mainly to the presence of abnormal wood characteristics, viz. growth stresses, tension wood and wetwood. The high level of growth stresses not only causes end splitting in logs requiring considerable trimming, but also can cause the distortion of logs and boards upon sawing, which necessitates resawing in order to obtain a marketable product.

Tension wood is characterized by the presence of libriform fibres which have a thickened secondary wall. These shrink more in longitudinal direction than the normal wood tissue. This characteristic can cause twist and crook during drying.

Wetwood mainly occurs in the zone between sapwood and heartwood. This zone has a moisture content much higher than the surrounding normal wood. Wetwood is reported to be susceptible to collapse, splitting and checking during drying (Mackay, 1974). Another characteristic of wetwood is that it dries slowly and is still wet when the normal wood is dry. This can cause large variations in moisture content between and within the boards after completion of the drying cycle.

A major research effort has been undertaken to examine ways to reduce the effects of abnormal wood in poplar. The work previous to this study is presented in Chapter 2. However, other studies regarding the drying characteristics of populus hybrids are still limited.

The objective of this investigation was:

1. To determine the general characteristics of Populus "androscoggin" grown in river bed plantations near Timaru. The characteristics considered included: diameter over bark , diameter under bark , bark thickness, heartwood diameter and eccentricity of the trunk.

2. To identify the relationship existing between the variables, so that one variable (the dependent variable) can be predicted by other variable (the independent variable).

3. To determine the distribution of the physical characteristics: green moisture content, green density and basic density between and within the tree of Populus "androscoggin".

4. To determine the drying characteristics of poplar using a variety of drying methods in order to reduce the effect of tension wood and growth stresses on sawn timber.

5. To determine the effect of the drying methods on the quality of the remanufactured boards for asparagus containers.

6. To determine a drying schedule suitable to produce boards for asparagus containers.

II. LITERATURE REVIEW

2.1 Wood water relationship

2.1.1 Why wood must be dried before use

Wood is an hygroscopic material which means that wood has the ability to adsorb or loose water by evaporation in response to changes in humidity and temperature conditions. The wood will loose moisture in a dry climate, and dry wood will adsorb water in a humid climate. This variation affects some of the properties of wood, for example its dimensional stability. Wood will swell and shrink as its moisture content increases and decreases in the range from ovendry to fibre saturation point.

The most important reason for drying lumber is to minimize dimension change after the wood is in service (Bramhall, 1981). Carelessness at the drying stage may make subsequent manufacture unsatisfactory and can result in failure when the product is used.

Some other reasons for drying wood include:

a. Strength properties

Most strength properties of timber increase when it is dried. This is due to the fact that the adsorbed water between the microfibrils in the cell walls and in the middle lamellae separating the cell can act as a lubricant thereby permitting a certain amount of slip. If the water is removed the frictional resistance increases leading to an increase in stiffness and strength properties.

b. Decay

The susceptibility wood to insect and fungal attack decreases on drying. On drying to 22% or less wood is resistant to some forms of fungal attack. Wood with a moisture content below 10% can be protected from some insects (Bramhall, 1976). The spores which already exist in the wood will be destroyed if dried at temperatures above 150 ^{o}F (65 ^{o}C).

c. Preservative treatment

Dry wood at and below 30 % moisture content is much easier to treat with preservative by pressure impregnation. Preservatives need passage ways to enter the wood. A moisture content of 25 - 30% is quite suitable for impregnating timber, while a somewhat lower moisture content may be desirable for timber that is to be treated by a surface application of preservative (Findlay, 1985).

d. Dried wood is more securely fitted and fastened together with nails, screws and adhesives.

e. Transport

The transportation cost for dry wood will be lower than that for green wood.

2.1.2 How water is held

Wood as part of a living tree contains a large amount of water. This water is essential for transporting the nutrients from the roots to all parts of the tree. The water in wood remains considerable until the timber is cut. The moisture content of freshly cut timber varies considerably between species, individual trees and between parts in the same tree. Bramhall (1976) noted that, based on the ovendry weight, the moisture content of freshly cut timber ranges from 35% in some heartwoods to 200% in sapwood.

The water in green lumber is held in two forms namely "free water" and "bound water". Free water occupies the cell cavities, whereas bound water is in the cell walls. Free water is easier to evaporate from wood and does not influence the properties of the wood.

Stamm (1964) stated that while some bound water may be held in the pre existing capillaries within the cell wall , this amounted to less than 2-4 % of the cell wall volume. The remaining fraction of bound water in the cell wall is present in the transient capillaries or spaces that exist only in the presence of water.

To remove the bound water from wood more energy is needed than to remove free water. In addition, the evaporation of bound water influences the mechanical and physical properties of wood, e.g. shrinkage takes place when bound water is removed from wood. The condition where all of the free water has evaporated from the lumen while the cell wall remains swollen with bound water is called fibre saturation point (FSP).

2.1.3 Water movement in wood

In the drying process, water in the surface will evaporate first. This evaporation causes the moisture content in the surface zones to become lower than that further inside and the water will flow from interior to the surface. The water in wood moves down a moisture gradient.

Initially the water that flows to the surface and evaporates is the free water. The drying process will continue until the moisture content is in balance with the surrounding conditions. This condition is called the equilibrium moisture content (EMC)

The evaporation of moisture from the wood surface creates a moisture gradient between the surface and the interior of the wood. This can set up a capillary tension that exerts a pull on the free water in the zones beneath the surface and a flow results. Mass flow is the bulk flow of fluids through the interconnected voids of the wood structure under the influence of a total pressure gradient. The pathways for this movement in the wood is through the cell cavities and pits or small openings in the cell walls. The continuity of voids in the pathway is very important otherwise mass flow will not occur.

The movement of bound water in low temperature drying (below the boiling point of water) is mainly down the moisture gradient through the cell walls and cell cavities. Hart (1975) noted that bound water diffusion across the cell wall followed by vapour diffusion across the lumen to the next cell wall is the pathway of major importance. Unlike mass flow movement, the rate of diffusion is predominantly influenced by the amount of cell wall material to be crossed rather than by the continuity or presence of openings.

In high temperature drying the movement of bound water may be by mass flow if there is a continuity of the voids which provides continuous pathways for the water. At temperatures above the boiling point of water, the bound water can convert into steam at a pressure above atmospheric. This pressure can cause the movement of water vapour (originally bound water) from the interior to the wood surface.

2.2 Factors Affecting Drying Rate

2.2.1 Wood properties

2.2.1.1 permeability

Permeability is a measure of the ease with which fluids flow through a porous material under the influence of a pressure gradient (Siau, 1971). The permeability is greatly depend upon the continuity of the voids within the material. Therefore the term permeability differs from the term porosity.

Porosity is the volume fraction of void space in a solid. A material must be porous to be permeable (but it does not follow that a porous body is permeable). Permeability can only exist if the void spaces are interconnected by openings (Siau, 1971).

Permeability is one property that is important in the drying of wood. In low temperature drying this property influences the water movement from the green to fibre saturation point. In permeable woods the flow of free water is influenced by capillary forces as air bubbles within the wood expand. The drying rate can be quite fast. In impermeable woods the movement of free water is restricted to diffusion, so the drying rate is slower than in a permeable wood.

The permeability of wood is not only important for the movement of free water as mentioned above but it also influences the rate of movement of vapour diffusion below fibre saturation point on drying at high temperature (above the boiling point). Stamm (1960) has shown that continuous vapour diffusion in sitka spruce from fibre saturation point to the ovendry state appears to contribute about 10% of total moisture movement. Since there must be a continuous flow path available to permit vapour to diffuse from one zone to another, Hart (1975) stated that pure vapour diffusion is only effective in permeable wood

The effect of permeability on moisture profiles can be seen in the diagrams below (Figure 2.1).

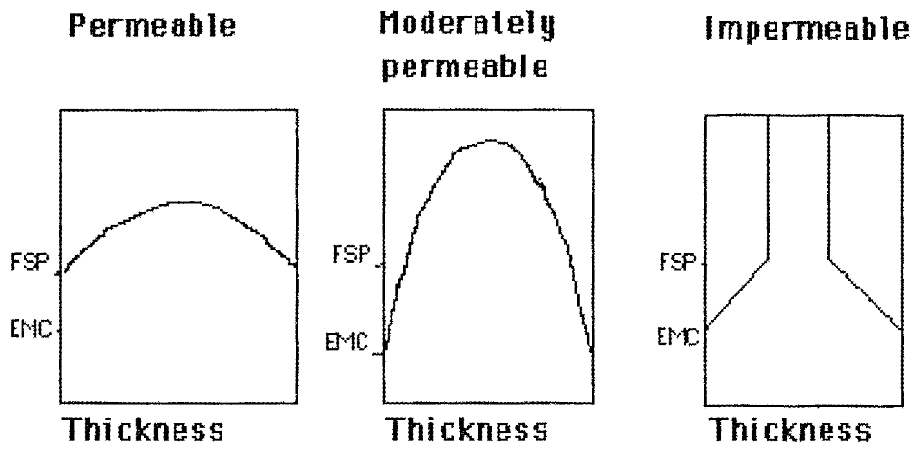


Figure 2.1 The moisture profile in the permeable, semi permeable and impermeable wood (Hart, CA, 1975)

A completely impermeable wood lacks continuous voids, so no mass flow of free water can occur, leading to the type of moisture gradient as illustrated in Fig.2.1. In both highly and moderately permeable wood, substantial mass flow of free water is occurring. The difference is that in the latter case the rate of surface evaporation has exceeded the rate of mass flow of free water to the surface, causing the surface fibres to dry below fibre saturation point This permits the surface temperature to increase, thereby reducing the temperature differences between the surface and the air. The rate of heat transfer from the air to the surface decreases correspondingly and the rate of moisture loss from the surface decreases by the same proportion.

2.2.1.2 Hardwood and Softwood

Basically, the property that most influences the drying rate is the wood structure. For example the continuity of the voids in the structure of wood is so important for the drying rate above fibre saturation point. The wood structure varies considerably between species, between hardwoods and softwoods and at least quantitavely between different parts of wood in the same tree.

Softwoods or gymnosperms are formed predominantly of tracheids (93%) with only a small percentage of parenchyma present (Meylan and Butterfield, 1980), whereas hardwoods or angiosperms contain a greater variety of cell types including thick walled fibres.

Tracheids function in the living tree of softwood for conduction of water and dissolved nutrient. In timber this cell type is essential as a path for the movement of moisture, because the tracheids are interconnected by pits. On the other hand the passage ways for the movement of moisture in hardwoods is through a variety of cells including vessels, tracheids etc, so the movement of water in a hardwood is more complex than that in a softwood.

Hardwood tracheids are generally thin walled and easily penetrated, but are usually a low volumetric fraction of wood tissue and therefore not of great important as a flow path (Siau, 1971).

In hardwoods the vessels or "pores" are sometimes visible to the naked eye. These vessels are build up of individual vessel elements joined end to end which usually have an opening (perforation plate) between the individual elements which provide a pathway for the conduction of water.

Unfortunately in hardwoods tyloses are frequently found which may greatly increase the resistance to or interrupt the flow of water. Tyloses are cellular membranes which enter the vessel from adjacent parenchyma cells through pit pairs (Siau, 1984). They are found most commonly in heartwood vessels though they also occur in sapwood vessels at sites of injury and more rarely in undamaged sapwood (Meylan and Butterfield, 1980).

2.2.1.3 Sapwood and heartwood

Sapwood is secondary xylem where the cells are active in conduction and the physiological activities of the wood are performed by living axial and ray parenchyma and fibres. Since the function of sapwood is conduction, sapwood usually contains a large amount of water. The transition to heartwood is marked by the deposition of extractives and other extraneous materials in the cells, and in the case of hardwood by the accelerated production of tyloses. The death of living cells then follows so that heartwood is physiologically dead tissue (Meylan and Butterfield, 1980).

Because heartwood contains extractives and other resinous materials (and in the case of hardwoods heartwood may also contain tyloses which can block the flow of moisture), usually heartwood is less permeable than sapwood. Therefore the drying rate of heartwood is slower than that of sapwood. Because of this variation, the heartwood of certain species need a different drying schedule than that for sapwood. In addition heartwood tends to surface check and honeycomb so that heartwood usually needs a milder schedule than does sapwood.

2.2.1.4. Moisture content

The amount of water in a piece of wood is known as its moisture content. The moisture content is usually expressed as a percentage of the mass of the water to the ovendry weight of the wood. Since the moisture content is based on the ovendry weight of wood, the mass of water in a piece of wood at a given moisture content depends on the density of wood itself. At the same percentage moisture content, the higher the ovendry density the more water the wood contains. The greater the quantity of water, the more there is to remove. The more water to be removed the longer the time needed to dry to a given moisture content.

Moisture content influences the rate of mass flow and diffusion in wood. Bramhall (1976) stated that in capillary flow (mass flow) the higher the moisture content the faster the movement of water. Similarly, under steady state conditions the diffusion coefficient increases exponentially with moisture content, so the moisture movement will increase correspondingly with the amount of water in wood.

2.2.1.5 The thickness of wood

The thickness of a board directly influences the drying time. The thicker the board the greater the distance water must migrate from the centre to reach the wood surface. Therefore the drying time will increase. The heat transfer from the surface to the centre of the board also will take longer in thicker boards.

Hart (1975) noted that the increase of moisture diffusion is inversely proportional to the amount of cell wall that must be traversed, and the amount of cell wall is directly proportional to both the board density and board thickness. So if removal of moisture from the surface is the sole limiting factor, drying time is directly proportional to board thickness and density. If moisture diffusion through the wood is the sole limiting factor the drying time is directly proportional to the board thickness squared and the board density squared.

2.2.2 External Condition

There are three major external parameters that influence the drying rate of wood; temperature, humidity and air velocity. It is important to understand how these three factors interact with each other in the drying process, in order to dry wood as quickly as possible. Hart (1975) considered two situations: when the surface of wood remains relatively wet, the rate of drying may be substantially increased by increasing airflow. On the other hand, when the surface approaches the equilibrium moisture content, the rate of drying is almost completely dependent upon the rate of moisture movement from the interior to the surface, and an increase in air velocity is ineffective and wasteful.

2.2.2.1 Temperature

Temperature is the first external factor that must be considered in the drying process. Temperature can affect the drying rate. The energy for air drying at ambient temperature costs nothing since it is obtained directly or indirectly from the sun. On the other hand in kiln drying the source of heat is costly and can be obtained directly by heating up the air or indirectly through a heat exchanger.

In drying, the energy that is required to evaporate the moisture present in wood is at least 2.25 megajoules/kg of free water present (Bramhall, 1976). This energy is adsorbed by the wood surface from the circulating hot air stream and transported to the interior of the wood. The heat that is adsorbed by wood can be used to increased the temperature of the wood and the water. The probability that the absorbed or adsorbed water molecules have sufficient energy to escape from the surface into the vapour will increase as the water temperature increases (Skaar, 1972).

Temperature affects the rate of moisture movement within the wood. When the movement of moisture through the wood is governed by a pressure gradient, the volume of fluid flowing down the "tube" is governed by Poiseuille's law:

$$dv/dt = (N\pi(P1 - P2)R^4)/(8\eta l)$$

Where, P1- P2 = Pressure differentials (Pascals/cm^2)

N = number of uniform circular capillaries in parallel

η = viscosity of moisture in wood(Pascals sec/ cm2)

R = the radius of capillary (cm)

From this equation it is clear that the flow of water will increase if the total pressure within air bubbles inside the wood is increased. The pressure gradient will be increased by increasing the temperature of water, so the rate of mass transfer will increase too.

Also from the equation, it can be seen that the rate of flow is inversely proportional to the water viscosity, i.e., it will increase if the viscosity decreases. Bramhall(1976) noted that a higher wood temperature can reduce the water viscosity, so that under a given capillary pull the water will flow more rapidly. A rise of wood temperature from 70 ^{o}F (21 ^{o}C) to 210 ^{o}F (99 ^{o}C) reduces viscosity by a factor of 3.

In the diffusion process, temperature dramatically affects the ease of diffusion in the same proportion as the vapour pressure increase, from 1 psi (0.97 kg/cm^{2}) to 14.7 psi (14.26 kg/cm^{2}) as the temperature increase from 100 ^{o}F (38 ^{o}C) to 212 ^{o}F (100 ^{o}C) so the rate of diffusion should be 14.7 time as fast as at the higher temperature (Bachrich, 1980).

Beside affecting the rate of moisture movement within the wood, the temperature also affects the capacity of the air to adsorb water vapour and hence the drying potential. Increasing the temperature means an increase in the absolute humidity of the air (the number of grams of H_2O per m^3 of air increases). The greater the carrying capacity of the air the smaller the quantity of air that needs to be vented from the kiln.

The effect of temperature on the drying rate is shown graphically by Pratt (1976). This is shown in Figure 2.2.

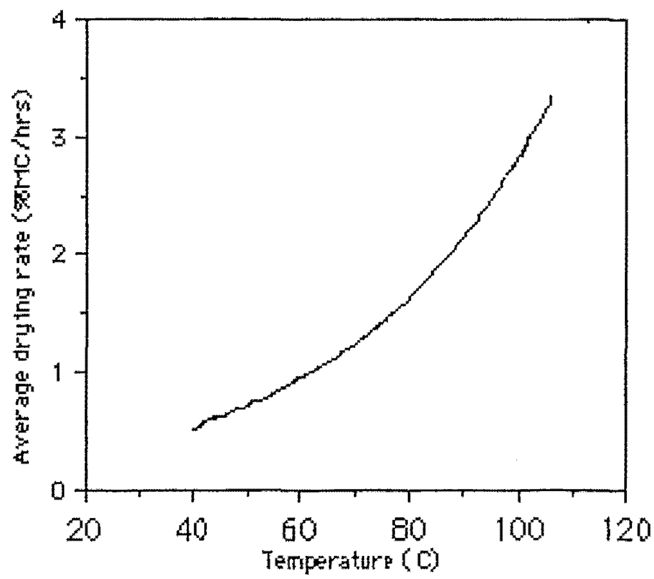


Fig 2.2. The relationship between the drying rate and the temperature at a given relative humidity (70%) and constant fan speed, source Pratt (1976).

2.2.2.2 Relative humidity

The relative humidity at a given temperature is expressed as a percentage of the ratio of the mass of water vapour per unit volume of air to that which would be present at saturation point, or the ratio of the partial vapour pressure in the air to the saturated vapour pressure (Siau, 1984). In practice the relative humidity can be measured directly by hygrometer or indirectly by the relation between dry bulb and the depression of wet bulb.

The relative humidity of the air is an important factor which needs to be considered in wood drying. Too low a relative humidity in combination with high temperature and high air velocity can cause excessive degrade. On the other hand, too high a relative humidity in combination with low temperature and low air velocity means the conditions are such that the wood is susceptible for destroying fungi.

The relative humidity of air greatly influences the equilibrium moisture content of the wood. So in the initial drying process the low relative humidity is avoided, since this condition can cause the surface of wood to reach a low equilibrium moisture content, shrinking too fast which can lead to drying defects such as checking, splitting, collapse etc.

The effect of relative humidity on the drying rate is very important when the surface of the wood remains wet (above FSP). When the wood surface is very wet, this can behave like the wick in the wet bulb thermometer. The "driving force" for water evaporation is determined by the vapour pressure differential between the wet surface of the wood and the surrounding air. If the surrounding air is saturated, no evaporation will take place and the wet bulb temperature corresponds to the dry bulb temperature. If the surrounding air is partially saturated, evaporation will take place. The greater the vapour pressure differential, the greater the "driving force" which will cause evaporation from a wet surface (Bachrich, 1980).

When the wood surface becomes drier because of evaporation, its vapour pressure will decrease too. With constant dry bulb and wet bulb temperatures, the "driving force" that creates evaporation will also decrease. Bachrich (1980) suggested that in kiln drying this problem can be overcome by:

1. Increasing temperature
2. Decreasing relative humidity.

Both measures will increase the vapour pressure differential and therefore increase the potential to dry wood.

2.2.2.3 Air circulation

Air circulation as well as heat and relative humidity influence the drying rate of wood. Without air circulation the heat and the humidity cannot reach the surfaces of wood which contain the water to be evaporated. Hilderbrand (1970) stated that for uniform and rapid drying a sufficient, strong and uniform circulation within the timber stack is required. Drying time and drying quality greatly depend on the manner of circulation of air, and also on the air velocity and its uniformity. Bachrich (1980) sums up the function of air circulation in drying process:

1. to supply sufficient heat to warm the lumber pile
2. to supply sufficient air to effect the required rate of evaporation
3. to accomplish point 1 and 2 with reasonable uniformity

At the beginning of drying, a considerable amount of water is being evaporated and, as a result the drop in air temperature across the timber stack is very large, and the humidity of the air increases almost to the saturation point. Under these conditions, for rapid drying the air velocity should be high. On the other hand, when the surface of the lumber has been dried below the fibre saturation point, the rate of evaporation is reduced. Under these conditions, a much reduced air velocity is acceptable. For these reasons the use of variable speed fans would be advantageous (Bramhall, 1976).

Since the air is cooled and becomes wetter as it picks up moisture, its ability to dry the lumber become progressively less as it passes through the load. By increasing air velocity, the lumber near the exit side of a load will receive hotter, drier air than if the air velocity were lower (Bramhall, 1976).

From the discussion above it is clear that the air velocity is quite important in the drying rate. The air velocity through the lumber pile is influenced by the thickness of the stickers or the vertical gap between the boards. The air flow through a certain area can be expressed by the equation below:

$$Q = V \quad A$$

,where Q = quantity of air pass through the area (cm^3/sec)
V = velocity of the air (m/sec)
A = the area or the opening for the air (m^2)

from the equation it is obvious that if the supply of the air remains constant (e.g from the fans), the velocity of the air is mainly influenced by the opening or the gap. In lumber piles this mean the thickness of the stickers. It appears logical that air velocity will increase if stickers were made smaller. Bachrich (1980) stated that the condition above is not necessarily true. As the sticker size decreases air turbulence is also increased. Consequently resistance to air flow is increased and air volume and rate of drying may suffer even if velocity is increased. For all practical purposes, sticker thickness of 18 mm will be assumed as a standard.

2.3 Method of Wood Drying

The drying method can be divided into two main types: first without control of the external condition (air drying) and secondly with control of the external conditions (temperature, relative humidity and air velocity) that influence the drying rate.

2.3.1 Air drying

In air drying the wood is subjected to open air, but possibly under cover. There is no control over the factors that determine the local climate, therefore the drying time greatly depends upon the rainfall, wind, humidity, and direct sunshine.

This method is widely used because it is simple in practice and does not require any special skills. Also air drying does not require the additional energy (e.g from boiler). This method can be economic in areas which have a moderate annual temperature and not too much rain (Brown, 1965)

There are other advantages of air drying over kiln drying. First there is a low initial cost, although there are substantial land, installation and operating costs for air drying (McMillen and Wengert, 1978). A second advantage is substantial energy saving. Each percent moisture removed by air drying saves energy in subsequent kiln drying by roughly 22000-37500 KJ/m^3. A conventional kiln with capacity of 120 m^3 can saves 2.6 - 4.5 million KJ for each 1% lost by air drying (McMillen and Wengert, 1978).

As there is no control over the external drying conditions, this method has several disadvantages. The disadvantages are mainly associated with the lack of control. Sometimes the drying condition can be unsuitable for drying of wood (high humidity, low temperature, lack of wind), sometimes conditions can be too severe, whereby the drying rate is too fast leading to drying degrade such as surface checking and splitting. The second disadvantage relates to production scheduling. The production schedules depend on the variable climate (Rietz, 1971). The other disadvantage of this method is its inability to produce wood with a moisture content as low as required because the final moisture content in air drying depends on the natural equilibrium moisture content of the area where the air drying takes place.

Because of these limitations air drying may have different objectives, for example:

1. As a pre-drying method prior to kiln drying. Usually air drying takes the timber from green to fibre saturation point and then by kiln drying to the final moisture content

2. Drying before preservation

3. Preparation before shipment. The loss of some moisture from wood means less weight and

therefore the cost for shipment will be reduced

4. For final uses which do not need low moisture content such as wood for use out of doors.

There are two fundamental principles to be followed in order to minimize the disadvantages or limitations of air drying, the first is that air movement must be positive throughout the stack so as to ensure uniform drying and the second to ensure the stacks are erected in such a manner as to eliminate costly degrade in the form of bowing, cupping, end splitting and surface checking (Brown, 1975).

As mentioned before, the direction of air movement and the air velocity depend on the prevailing wind. One way to maximize the effect of air movement in order to gain the most effective drying rate is by manipulating the arrangement of the wood stack based on experience of the behaviour of local winds.

Warm air tend to rise and cold air tend to fall. In air drying the warm air entering the pile picks up the moisture from the wood and is cooled tending to drop to the bottom of the stack, For this reason, stacking of lumber for air drying require a gap between adjacent boards to let the cooled air drain down through the stack. Fresh warmer air is thereby drawn into the stack.

Finighan and Liverside (1972) made a study to find out the effective arrangement of the pile, such as the effect of stack, road width, stack placement pattern and the orientation with respect to prevailing wind. The result showed:

- the variation in evaporative losses is smallest when stacks are parallel to the wind
- the average evaporation is greatest when stacks are at right angles to the wind
- top packs have a higher evaporative loss than bottom packs
- foundation height or design does not greatly influence the air movement pattern.

The other factor that should be considered in air drying is the drainage of the lumber yard, because a damp area can cause an increase in the relative humidity, therefore the drying rate will suffer.

2.3.2 Kiln drying

Kiln drying is carried out in a closed environment which consists of one or more chambers or a tunnel in which air is rapidly circulated over the surface of the wood being dried. One of the advantages in kiln drying is that the operator has the ability to control the temperature and the relative humidity of the circulating air within the kiln to suit the condition of the timber being dried at any given time. The other advantages are :

- can produce better timber quality than air dried timber
- faster drying time
- can dry the wood to final desired moisture content
- the room can be conditioned to relieve residual stresses
- the production schedule can be predicted.

Kiln drying can be divided into two categories: progressive kilns and compartment kilns. In the progressive kiln, the timber being dried is moved progressively from the humid and low temperature entrance to the drier towards the higher temperature zone near the exit. In compartment kilns the timber remains stationary. The temperature and relative humidity inside the kiln is changed during the drying schedule, based on the schedule that is being used. Pratt (1974) stated that compartment kilns are more accommodating in that a wide variety of loads can be accepted and each given appropriate drying treatment.

2.3.2.1 Principals of kiln drying

As mentioned before, in kiln drying all external factors can be controlled in accordance with the properties of the timber being dried. Rasmussen (1961) noted that the temperature and relative humidity can be manually or automatically maintained by controlling the dry bulb and wet bulb temperatures.

Heating which is needed to keep the temperature in accordance with the schedule is usually supplied by steam coil or radiator or by a heater using electric power. The total heat required in kiln drying is not only used to heat the wood but also to warm the building and kiln machinery to the operating temperature (Bachrich, 1980).

Relative humidity is usually controlled using a wet bulb sensor. Two devices are employed in order to control the relative humidity in the room, namely ventilation and humidification. Ventilation of the kiln chamber by air interchange through adjustable openings in the structure must be provided in order to keep humidity down to the required level when large quantities of moisture are being rapidly evaporated from the timber. Humidification is sometimes needed to keep the humidity at the desired level when moisture coming from the wood is insufficient to do this. It is particularly needed towards the end of the kiln schedule and is essential for applying the final high humidity treatment.

Air circulation is required to convey heat to and moisture away from all parts of the kiln. The distribution of the air should be uniform to all parts of the room and through the timber being dried. Beside uniformity, the air should have enough velocity to distribute it throughout the stacks. In the case of wide stacks of timber, usually the direction of air flow through the fans should be reversed every few hours. Hildebrand (1970) stated that the most economical air velocity is about 2 m/sec, and air velocity of 3 m/sec or more is only advantageous economically in certain cases (for wet timber or high temperature drying of sawn timber).

2.3.2.2 Kiln schedule.

A kiln schedule can be considered as a general guide as to how the conditions in the kiln drying can be adjusted as the wood is dried. The drying schedule consists of a set of temperatures and relative humidities according to the moisture content of wood. This schedule varies between species which have different drying characteristics. Usually the drying schedule for a certain species is obtained by experiment and experience.

Bramhall (1976) noted that the schedule can be divided in to two types, moisture content based and time based. The moisture content based procedures require determining the initial moisture content of the charge and repeated moisture content determinations to determine when the schedule changes should be made. It is possible to convert the moisture content based schedule to a time based schedule once one has had some experience with drying the timber. Time based schedules obviate the necessity to make moisture content determinations during the the schedule running. Unfortunately time based schedules usually contain no reference to the initial moisture content.

Kiln schedules can be divided into three broad categories: low temperature, conventional drying and high drying schedule.

a. Low temperature drying schedule

Bramhall (1976) stated that the low temperature kiln schedules are used primarily for temperature-sensitive timber and particularly for hardwoods. In addition low temperature drying can be used when it is impossible to reach the temperature specified because of a shortage of heat and/or steam capacity, or where the kiln building was not designed for high temperature use (Kinninmonth and Williams, 1974).

The maximum temperature that is used in this schedule is about 140 ^{o}F(60 ^{o}C).

An example of a low temperature drying schedule quoted from Kinninmonth and Williams (1974) is shown below.

Table 1. Low temperature drying for rimu, thickness 25 mm.

Moisture Content (%)	Temperature DB (°F/°C)	WB (°F/°C)	RH (%)	EMC (%)
Green	120/49	110/43.5	75	13
90	125/51.5	110/43.5	63	9.7
40	130/54.5	119/43.5	51	8.0

b. Conventional schedules

Conventional drying schedules are widely used both for hardwoods and softwoods. Lumber quality is easy to maintain, particularly where final equalizing and conditioning is used. Conventional kiln drying uses temperatures up to 212 °F (100 °C), although they are usually in the range of 140 - 190 °F (60 - 80 °C). These systems include steam heated dry kilns and certain electric dehumidification driers (Wengert and Lamb, 1988). Kilns are generally made from well insulated concrete blocks or prefabricated aluminium panels.

The example of conventional drying temperature (without conditioning period) for Populus tremula suggested by Brown (1965), Bachrich (1980) and Pratt (1974) can be seen on Table 2.

Table 2. Conventional drying schedule for <u>Populus tremula</u>

Moisture Content (%)	Temperature DB (^{o}F/ ^{o}C)	WB (^{o}F/ ^{o}C)	RH (%)	EMC (%)
Green	120/48.5	115/46	85	16.1
60	120/48.5	113/45	80	14.0
40	125/51.5	116/46.5	75	12.7
30	130/54.5	117/47	65	11.0
25	140/60	120/49	55	8.0
20	155/68	127/53	47	6.2
15	170/76.5	136/58	40	5.2

c. High temperature drying schedule

The temperature used in high temperature drying is above 212 ^{o}F (100 ^{o}C) or above the boiling point of water. This schedule is restricted to the permeable and semi permeable woods, usually softwoods which are more resistant to drying degraded. The advantages are that less energy is used and faster drying achieved. The disadvantages include an increased risk of overdrying and degraded in the lumber due to increased temperature (Bramhall, 1976). Wengert and Lamb (1988) stated that high temperature kilns require a large boiler, high air flow and well maintained and coated kilns. The other disadvantages are severe kiln conditions and lack of schedules for many species.

Table 3 shows an example of a high temperature drying schedule used by Huffman and Cech (1976) in their study of drying characteristics of <u>Populus tremuloides</u>.

Table 3. High temperature drying schedule for <u>Populus tremuloides</u>

Step	DB ($^oF/^oC$)	WB ($^oF/^oC$)	time (hr)
Warm up	-	201/94	2
green-7%	220/104.4	201/94	63
conditioning	205/96	201/94	3
		Total	68

2.4 Drying Defects: Causes and Prevention

Removing the moisture from wood has several advantages as mentioned before. However, these positive benefits can be negated by the serious defects that can appear in the wood while drying. For that reason the correct drying procedures needs to be established not only to ensure a rapid removal of moisture from the wood with a minimum expenditure of energy, but also to preserve the wood quality.

Most of the defects that occur during drying are associated with internal stresses. The internal stress may arise in several ways including severe moisture gradients, differences in shrinkage characteristics in regards to cell orientation (longitudinal, tangential and radial direction) (Skaar, 1972). It is impossible to avoid all drying stresses in wood. However, it is possible to avoid severe drying stresses which exceed the ultimate strength of the wood.

Surface checks, end checks, honeycombing, casehardening, warping and collapse are forms of defects that can occur during the drying process which are associated with internal stresses. The occurrence and prevention of these defects are discussed below:

2.4.1 Surface checks

The surface checks can occur when the rate of moisture evaporation from the board surfaces is in excess of the rate of moisture movement from the centre to the surface. The difference between the rate of moisture movement to the surface and evaporation can lead to a very steep moisture gradient between the centre and the surface of the board. When the surface moisture content falls below the fibre saturation point, shrinkage will take place at the surface, and if the moisture content in the centre is above fibre saturation point the internal stresses will occur: the outer layers of the wood will be under tensile stress. Hildebrand (1970) stated that if the tensile stresses perpendicular to the grain exceeds the tensile strength perpendicular to the grain, surface checking will occur.

Since the shrinkage in the direction of the growth rings is greater than that perpendicular to them, checking is most likely to occur in the faces of flat sawn cut and on the edges of quarter sawn material, usually along the rays (Pratt, 1974). In addition Rasmussen (1961) stated that wood is more prone to suffer these defects during the early stages of drying, when it is green and when the moisture gradients may be considerable, than during the later stages when a material is at a lower moisture content throughout.

Since the surface checks usually occur in the early stages of drying because of the severe conditions, kiln drying checking can be prevented by using a lower temperature and higher humidity at the beginning of the drying schedule. In air drying, checking may be prevented by protecting the wood from direct rain and sun e.g. using a shed.

2.4.2 End checks

The movement of water in the longitudinal direction is easier than the movement in the transversal directions (Pratt, 1974). In consequence the evaporation of moisture from the ends of the board is fast and the wood near the ends of boards has a tendency to dry and shrink faster than the remainder. This tendency may lead to sufficient drying stress to cause end checks.

Hildebrand (1970) suggested sealing or coating the ends of the boards with a moisture resistant paint or wax, so that end drying will be restricted and splitting thereby eliminated or reduced.

Furthermore, based on the study of the effect of end coating on high temperature drying, Rosen and Micelli (1980) suggested that the end coating should have adequate resistance to water movement under such conditions and humidity to resist blistering caused by expansion of water and air within the wood and yet be flexible enough to adjust to dimensional changes as the wood dries.

2.4.3 Honeycombing

Honeycombing is a check that occurs in the interior of a piece of a wood. Often these checks are not visible on the surface. This checking is usually the result of too high temperature at the beginning of drying. The high temperature can cause the rapid evaporation and stress development in the surface layers. If the stresses exceed the elastic limit, a "permanent set" or deformation tends to develop (Pratt, 1974). The outer zone will tend to "set" in an expanded condition and the inner in compression. When the centre parts dry below the fibre saturation point they will tend to shrink in excess of and be resisted by the expanded outer zones. Stressing will again develop, but now in the opposite sense to that initially with the centre in tension and the surface in compression. If the stresses become large enough the stretched fibres at the centre may be torn apart and the splits formed inside the material. This is called honeycombing.

Hildebrand (1970) suggested that honeycombing can be avoided by selection of the correct schedule. Also, because honeycombing usually occurs at high temperatures in the early stages of drying, one way to avoid this defect is by using a lower temperature early in the schedule.

2.4.4 Casehardening

Casehardening is a condition in which the outer fibres dry under a compressive stress and the inner fibre are under a tensile stress, these stresses persist when the wood is uniformly dried (Rasmussen, 1961)

The stress-time history for casehardening is almost as same as for honeycombing. During the initial stages of normal drying the surface dries below fibre saturation point and shrinkage takes place. However, this is resisted by the wet core which is still above saturation. The outer layers of the wood are under severe tensile stress whereas the inner layer are under a milder compressive stress. If these stresses occur for a long time it will cause the outer layers to become "stretched" or "set" in the tension and shrink less than they would if drying gradients did not exist (Skaar, 1972).

As drying progresses further the compressive stresses in the core increase as intermediate layers dry and start to shrink. The tensile stresses in the outer layers decrease because the adjoining layers also try to shrink relative to the undried interior and these adjoining layers begin to develop some tensile stresses. Later still, the core starts to dry and shrink and we get a situation in which the stresses are reversed. The outer layer is now in compression and it remains so through the subsequent drying time (Pratt, 1972). This occurs because the outer layer has been set or stretched severely in tension during the initial drying period compared with adjoining layers. Therefore, as the outer layer dry below fibre saturation they tend to shrink more parallel to the wide face of the board than the fibres adjoining the surface layer. This condition results in permanent residual stresses within the lumber after drying (casehardening).

Boards containing casehardening may remain flat and have no apparent degrade but if they are deep sawn or heavily machined the balance of stress within the material is disturbed and some distortion may occur (mainly cup).

The existence of casehardening can be determined by a prong test as shown in Fig 2.3. If there are any residual stresses, the prong will tend to curve outward or inward.

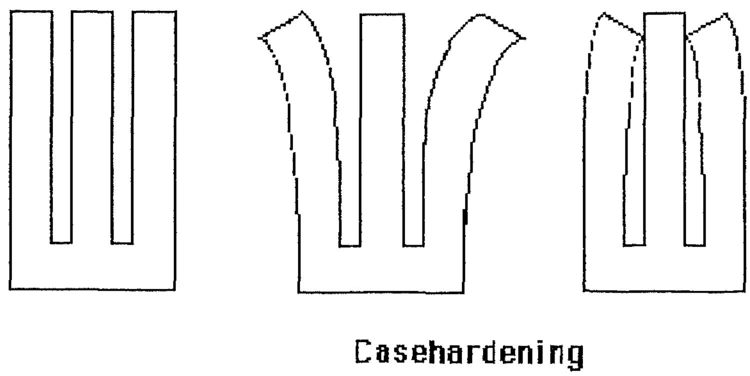


Figure 2.3 Prong test for determining casehardening in wood

High temperature and high humidity in the final stage of drying or a final conditioning period are recommended in order to relieve the residual stresses (casehardening). In conditioning the outer layer will gain moisture and try to expand, stresses and strains are thereby induced which are opposite to and so tend to neutralize those previously induced by the normal shrinkage.

2.4.5 Warping

All species of wood shrink to some extent when dried to a moisture contents below the fibre saturation point. The shrinkage is not equal in all directions due to the anisotropic nature of wood and this can lead to warp. This defect depends on a number of factors: species characteristics in controlling the occurrence of warp, radial and tangential shrinkage ratio, natural defects in wood such as knots, spiral grain, reaction wood and the amount of juvenile wood present.

The types of deformation are: bowing, crooking, cupping, twisting and diamonding. Bowing is defined as longitudinal curvature, flatwise from a straight line, drawn from end to end of the piece. Crooking by comparison is longitudinal curvature edgewise from the straight line drawn from end to end of the piece. Both arise as a consequence of differences in longitudinal shrinkage. The first is from differences in the shortening on the faces of a board, the second from a differences in shrinkage on the edges of a board (Panshin et al., 1964).

Cupping is the curving of the face of a plank whose the edges remaining approximately parallel to each other. Two primary causes of cupping: firstly the more rapid drying of one piece of a board than of the other and secondly the difference between radial and tangential shrinkage which causes one side of the piece to shrink more than the other (Panshin et al., 1964). Cupping may also result when casehardened lumber is resawn or is dressed more on one side than the other.

Twisting is the condition in which one corner of a piece of wood twists out of the plane of the other three. Twisting is usually a concomitant of cross or irregular grain (Panshin et al.,1964). Finally, diamonding describes the uneven shrinkage which usually develops in square dimension timber in which the growth increment extends diagonally so that the faces of the piece are neither flat or edge grained.

The forms of warp are illustrated in Figure 2.4

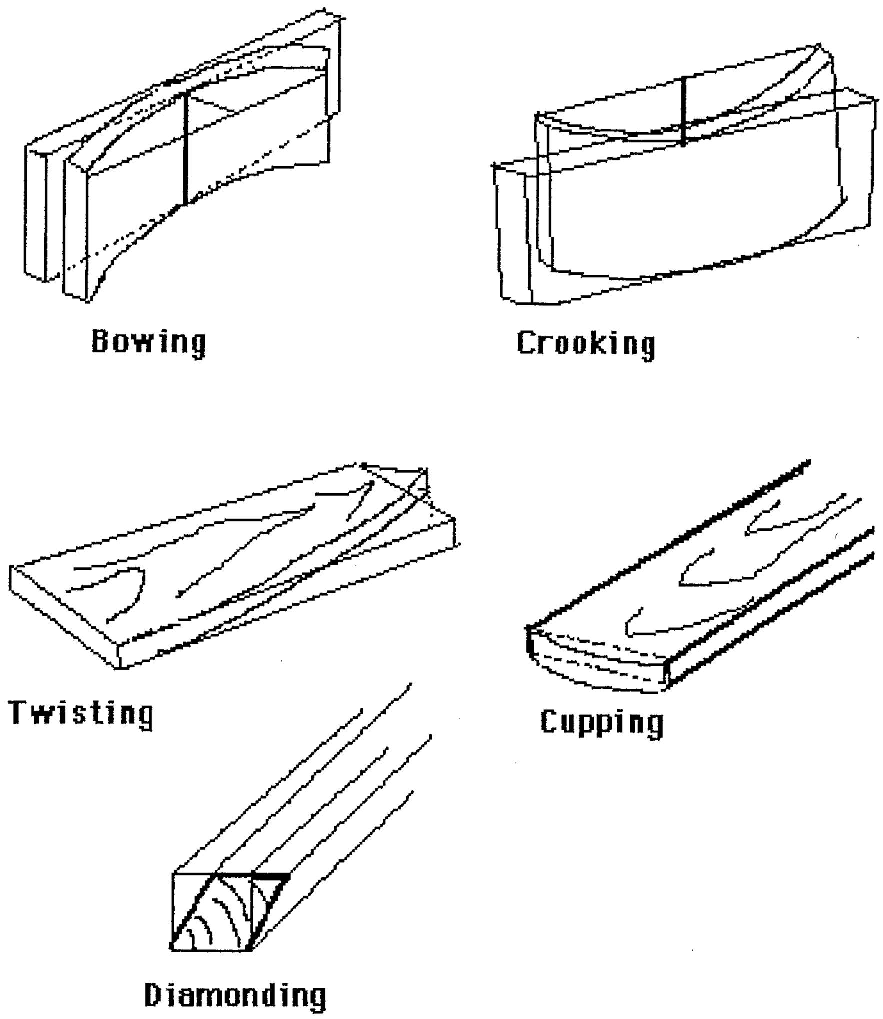


Figure 2.4 types of warping.

Simpson (1982) suggested four approaches to reduce warp, these are: restraint during drying, saw-dry-rip methods, modifying drying schedules and straightening warp after drying.

Drying under restraint depends on proper stacking, uniform board thickness, and applying a weight to the top of the lumber. McCay(1974) found that a 50 pound per square feet (48.5 kg/cm^2) top load was effective in reducing bow and twist in aspen studs. Koch (1974) developed an aluminium sticker with serrations that could be pressed into southern pine studs prior to drying. He found less crook, bow and twist in studs dried with the serrated stickers than in studs which had only been dried under a top load restrain.

Some sawmills use saw dry rip (SDR) methods, which involve live sawing, drying and finally ripping. This method does indeed help control warp. In a study of the effect of SDR on the quality of yellow poplar studs, Maeglin and Boone (1983) found that the SDR treatment produced warp in boards less than in conventional sawn and conventional drying treatment.

McCay, Hamm and Forchi (1977) developed a method to straighten crook in dried aspen studs. The studs are steamed and then loaded to deflect in the direction opposite to their crook. After a period of time, most of the crook is eliminated.

2.4.6 Collapse

Unlike other drying defects, collapse occurs before all free water has evaporated from cell cavities. Other defects are caused by the drawing together of the cell wall material as the water dries out from the walls, while in collapse the walls of the cell are actually pulled together causing the cells to buckle (collapse) in more or less extensive regions throughout the wood (Panshin et al., 1964).

Brown (1965) noted that collapse is caused by "liquid tension forces", whereas Panshin et al. (1964) and Rasmussen (1961) discuss two theories of collapse, the first is liquid tension and the second is the compressive stress theory.

In very wet wood, a number of cells may be entirely filled with water, with no room for air. As the cells dry, the capillary tension in the cell system will occur, and increase when the drying continue. The capillary tension may cause the cell walls to be drawn together (collapse).

Siau (1984) noted that collapse will occur if the capillary tension exceeds the compressive strength perpendicular to the grain.

The other theory postulates that collapse occurs when the compressive stress developed during drying exceed the compressive strength of the wood; as a result the fibre walls collapse into the fibre cavities.

Siau (1984) summarized the factors that are responsible for collapse of high moisture content boards:

1 small pit- membrane openings increases the susceptibility of the wood to collapse, due to the resulting high capillary tension.

2 high surface tension of the liquid evaporated from the wood promotes collapse. When free water is replaced by a low- surface -tension organic liquid, collapse may sometimes be prevented.

3 low density wood has thin cell walls which may collapse easily due to low compressive strength.

4 elevated temperature decreases strength and therefore render the wood more susceptible to collapse.

Some efforts have been made in order to relieve the collapse in wood, by subjecting the wood to a higher temperature and humidity for a period of time after it has been dried. In this case the air and water vapour in the wood exert a pressure inside the cells which reverses the tension forces that originally caused the collapse (Siau, 1984).

2.5 Poplar And Its Characteristics

2.5.1 General appearance

A general description of the sapwood of poplar is that it is creamy white in colour and the heartwood is greyish white to light brown. The wood is free from appreciable odour and taste, and is inclined to be woolly, but generally has fine and even texture with straight grain.

In the cross section of poplar, the pores of juvenile wood are visible under a magnifying glass, very frequent, widening out in bands. The pores of adult wood are barely noticeable, but much more thinly distributed than juvenile wood (Herpka, 1986).

2.5.2 Wood Anatomy

Poplar can be classified as a diffuse porous hardwood, about one quarter of its cross section appears as pores under low magnification. These pores are composed of long rows of tube-like vessel elements arranged end to end along the wood grain.

About two thirds of the wood volume is present in the form of fibres which, compared to the vessel elements are relatively long and thick walled. Fibre length typically doubles in value between rings close to the pith (0.50 to 0.70 mm) and more mature wood 15 to 20 rings distant. Longer fibres are associated with faster rates of growth at any given age from the pith (Kennedy 1974).

2.5.3 Physical properties

2.5.3.1 Moisture content

Standing poplar trees have a high moisture content, typically in the order of 100% with only minor differences between sapwood and heartwood. Seasonal fluctuations exist, such that moisture content in the summer may be 30 to 50% lower than that of late winter. Variations may also exist between species. Black cottonwood and balsam poplar generally have high amounts of moisture content. Seasonal and species variation, can have important implications on development and successful application of a consistent drying schedule (Kennedy, 1974).

2.5.3.2 Basic density

As a product of biological growth the anatomical characteristic of the fibre length, cell diameter, cell wall thickness and proportion of cell types vary with a host of environmental factors such as temperature, precipitation and wind. In addition such factors as age and position of the material in the stem (height and distance from the pith) influence these anatomical characteristics which in turn have an influence on the wood density.

The variation of wood density in poplar has been reported by many researchers. The results of investigations by Sing (1985) show the pattern of increased wood density in the tree of trembling aspen and balsam poplar related to height. Results showing changes in wood density relative to the height at which samples were taken from the tree stem were also reported by (Dawson, 1976) for 3 years-old populus grown under intensive culture.

In another study on the effect of management and site on selected properties of Populus "androscoggin" (NE-388) Blankenhorn et al. (1988) found that basic density decreased with increasing age. The management strategy was also found to influence basic density in 2 - 4 year old wood: in general, fertilization together with irrigation resulted in lower basic densities than the irrigation alone or in controls.

2.5.3.3 Permeability

A study to determine the variation in longitudinal and transverse gas permeability in poplar was conducted by Isaac et al. (1971), it showed that the variation in permeability in cottonwood (Populus deltoides)(using humidified nitrogen gas), varied with height in the tree, stem quadrant and radial location. Variation with height was irregular. The longitudinal permeability was highest adjacent to the corewood and then dropped rapidly toward the periphery of the tree (sapwood less permeable than heartwood). In the transverse direction of heartwood the radial flow was slightly higher than the tangential flow. Isaac et al. (1971) suggested that permeability could be correlated with basic density.

A different result from the study above has been observed by Pern (1985)on the study of permeability in aspen (Populus grandidentata). He found that sapwood has the highest permeability followed by heartwood and then the core (a few annual ring from the pith). This result was similar to the permeability that was found in other species (Choong and Fogg, 1968). Pern (1985) argued that in the first study by Isaac et al., where sapwood was less permeable than heartwood, it may have been caused by the cell wall in sapwood collapsing during seasoning.

2.5.4 Abnormal Wood

2.5.4.1 Tension wood

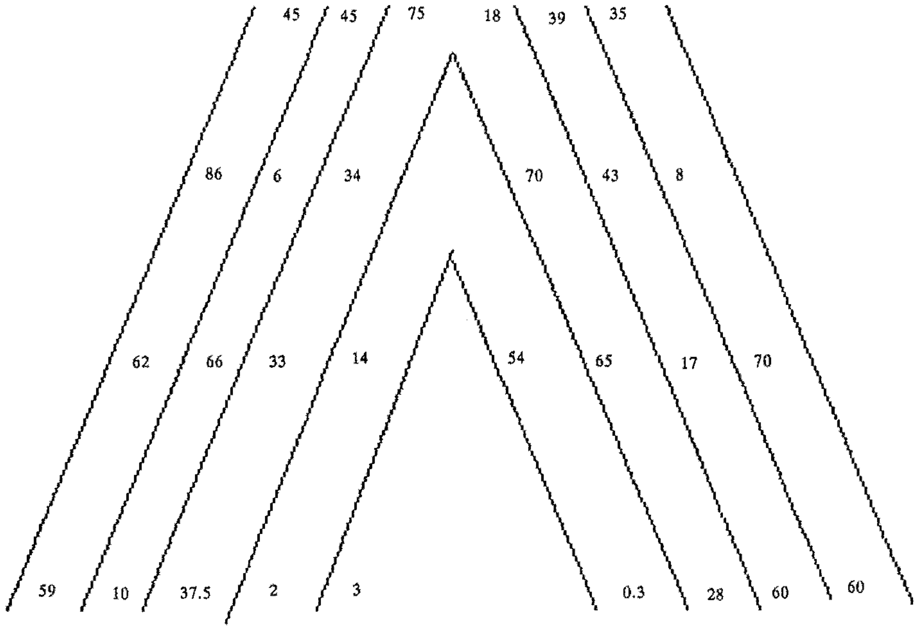
Tension wood is found extensively in poplar. It is associated particularly with the upper side of leaning stems and branches. Tension wood is characterized by masses of gelatinous fibres and a reduced vessel (pore) volume. It appears to develop in a living tree in reaction to deficiencies in growth hormones (auxin) or the presence of certain inhibitors (Kennedy, 1974).

The tension wood may be darker or lighter in appearance than normal wood. In poplar wood, it can be detected in a cross section by its snow-white colour, but very often these differences are difficult to see with a naked eye. Tension wood has a higher percent of cellulose and lower lignin content (Herpka, 1986).

From the determination of the relationship between the gelatinous fibre and the size and number of other elements within the wood, Kaeiser and Boyce (1965) found that in Populus deltoides the increase in the severity of the gelatinous layer was related to the decrease in diameter and the increase in wall thickness of the non gelatinous fibres. The relative sizes of rays, vessels and fibres was interrelated, so that all of these wood elements decrease in size with an increase in the severity of the gelatinous layer.

In a study to obtain basic information on the distribution of tension wood fibres in eastern cottonwood, Kaeiser (1955) found that at breast height the number of fibres having a gelatinous layer was greatest on the upper side of the leaning stem, with the lower part having the same or less than the lateral area. The investigation also showed that there is a relationship between the degree of lean of a trunk and the number of the fibres with the gelatinous layer present. The greater the lean the greater the proportion of fibres on the upper side that have a G-layer. A tree, with a lean of 12°, showed the highest proportion of G fibres (44%), whereas the tree with the lean 1° has the lowest comparative proportion of G fibres. Trees with 8° and 4-5° lean, respectively rank second and third correspondingly by lower proportion of G fibres (22 % and 16%).

An intensive investigation in <u>Populus deltoides</u> by Isebrand and Bensend (1972) revealed that the percentage of gelatinous fibres in the wood ranged from 0.51 to 97.87. All positions sampled had some fibres with a gelatinous layer even when the selected trees are straight/free from the lean. Also this investigation indicated that the distribution of gelatinous fibres in <u>Populus deltoides</u> followed no pattern. The actual distribution of gelatinous fibres for two examined trees (both are straight) are shown in figure 2.5. From the figure it can be seen that at a given height, one side of the annual ring had a high percentage of G fibres and the other side a low percentage, whereas at the next sampling, the same annual ring showed the opposite pattern. The uncertain pattern of distribution of gelatinous fibres in the straight tree also occurs in rapidly growing Populus spp (Isebrand and Parham, 1974).



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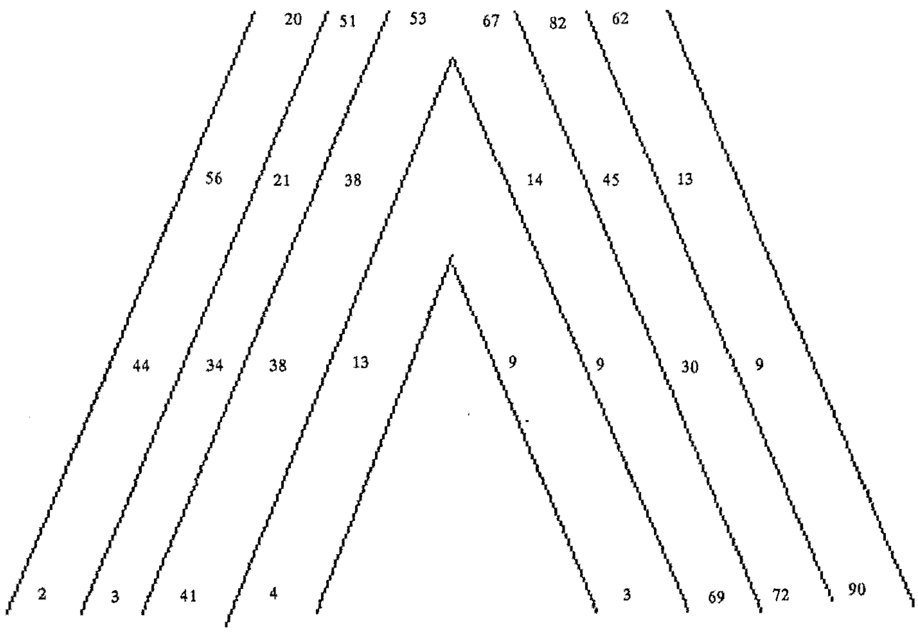

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Figure 2.5 The percentage of gelatinous layer within two trees of Eastern cottonwood.

Tension wood can cause difficulties in processing due to its high longitudinal shrinkage and ease with which fibres tear out when it is sawn or surfaced.

Rendle (1955) stated that there may be considerable difficulty in sawing logs containing tension wood, because gullets tend to become blocked with fibrous material and the teeth are quickly blunted. A rough and woolly finish is often produced when sawing green material since fibres tend to be partly torn out rather than cut cleanly. Furthermore Rendle (1955) suggested that there is no advantage in using a smaller cutting angle, the employment of the normal angle (30 degrees) and sharp tool are recommended.

When drying, it might be thought that the gelatinous layer would block the movement of water, but Marra (1942), quoted in Clark (1958) found that drying in hard maple proceeded faster in gelatinous fibered tension wood than in normal wood.

The main problem during drying is the high longitudinal shrinkage of the tension wood. This can lead to the warping of boards. From a study of the effect of tension wood on seasoning and machining of eastern cotton wood, Clark (1958) concluded that, compared to boards from normal wood, boards which contain tension wood bowed more,checked more, had more projecting fibres when planed, and had projecting fibres along sawn edges. Areas of projecting fibres were closely associated with deviation of the grain in the tension wood.

Conditioning treatment in drying effectively relieved casehardening in all of the lumber (Clark 1958). More collapse was noted in kiln dried lumber than in air seasoned lumber and this was associated with the presence of tension wood.

Finally Wahlgren (1957) and Clark (1958) suggested that with merchantable hardwood, it seems evident that marking the upper side of the tree would prove of great advantage during the sawing operation. With the upper side marked, the log can be sawn at right angle to the lean, obtaining high quality lumber from lower side. The boards from the upper side would contain a more uniform distribution of gelatinous fibres resulting in more longitudinal shrinkage and less warping. If the boards are cut parallel to the lean, it would be logical to expect that those boards would show differential longitudinal shrinkage and consequently would warp more upon seasoning.

2.5.4.2 Growth Stresses

All trees as they grow, develop stresses to some degree within the stem due to the changes in cell dimension. These stresses are technically important because of their effect during cutting processes and also they can reduce the product recovery. Stress distribution in both the longitudinal and transverse axes is a normal characteristic of growing trees and occurs in both hardwoods and softwoods (Dinwoodie, 1966). However, the magnitude of stresses varies between and within species.

Hallock (1966) noted that for hardwoods the longitudinal tensile stresses are frequently in excess of 7 MPa and for certain species of Eucalypts can be as great as 21 MPa. Compressive stresses are much smaller, in the range of 2.1-2.7 MPa.

The distribution of longitudinal stresses in large softwood trees is the same as the longitudinal stress distribution found in hardwoods of all diameters. The outer layer or the periphery is found to be in tension and the inner layer in longitudinal compression (Figure 2.6). In small (pole diameter and less) erect softwoods (e.g. Pinus radiata), there is a tendency for the outer layer to be in compression and the inner layer to be in tension (Jacob, 1945).

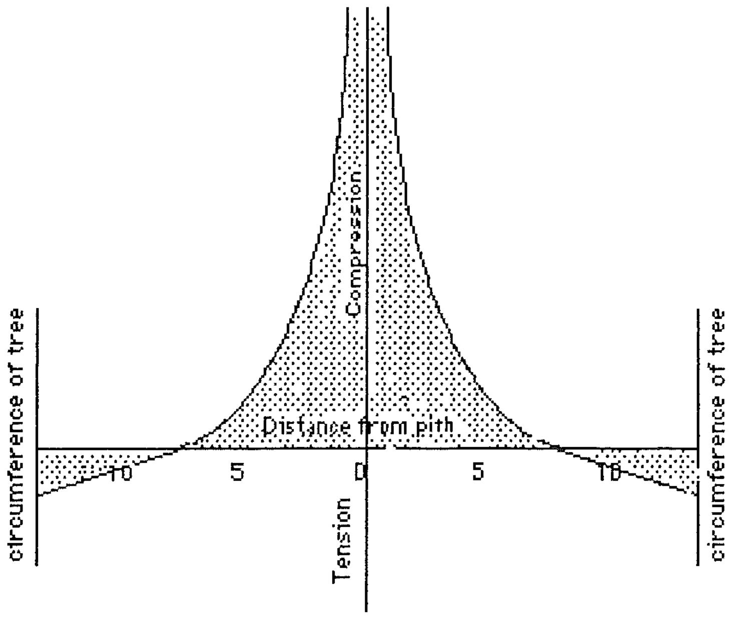


Figure 2.6 The distribution of longitudinal stresses in all sizes of hardwoods and large diameter of softwoods.

Further, Jacob (1945) reported that the distribution of transverse stresses both in softwood and in hardwoods was similar: tangential compression near the periphery and radial tension near the pith (Figure 2.7).

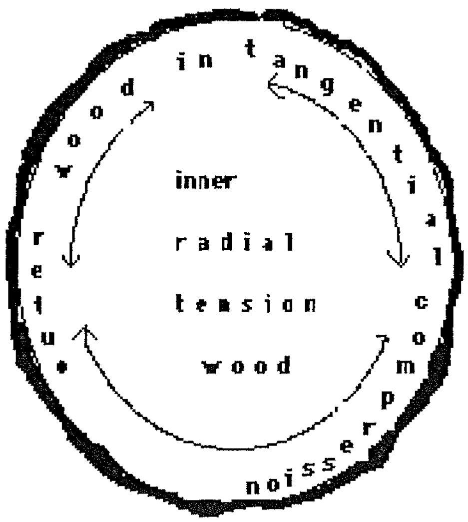


Figure 2.7 The distribution of transversal stresses in cross section.

The conversion of timber containing a high level of internal stress presents two major problems. The first is the physical difficulty of sawing the timber. The second is the financial loss due to timber degrade. In cross-cutting, the longitudinal compression in the core tends to close the kerf thus "pinching" or "binding" the saw. On ripping, there is again a tendency for the kerf to close due to high longitudinal compressive forces near the pith (Jacob, 1945).

All stresses and their corresponding strains are in a state of equilibrium in the log. The problem begins when the log is sawn to yield slabs, boards, flitches or other timber members. The balance of forces is upset and the sawing of each new piece generates a new balance in the stress-strain relationship. In hardwoods, the longitudinal tensile stress gradient increases from the pith outward, so the deflection of the lumber and the log from which it is sawn is convex with relation to the pith (Dinwoodie, 1966).

Boyd (1950 a) and Maeglin et al. (1985) stated that in standing trees the high internal stresses can result in the development of shakes. These take the form of star-shaped cracks in the core of the tree and run along the stem for some considerable distances. This is a result of both the high radial tension and longitudinal compression near the pith.

Wilhelmy and Kubler (1973), in the study of stresses and checks in log ends found that cross cutting of the tree stem transforms longitudinal growth stresses into transverse stresses, which cause heart checks at the end of thick logs. Transverse stress and strain due to the relief of longitudinal stress is heavily dependent on the distance from the cross cut face of the log. Close to the end face a large tensile strain appears near the pith where the heart checks start; toward the bark the strain decreases and turns into a slight compressive strain radially.

Based on the above distribution Wilhelmy and Kubler (1973) suggested that prevention of heart checks can be done by circumferential clamps or steel straps stretched around the stem at both sides of the cross cut.

There have been some studies to determine the best methods which reduce the detrimental effect of growth stresses. These efforts include silvicultural treatment and manipulation in processing prior to conversion. A silvicultural treatment investigation by Ferrand (1983) (which is quoted from Malan (1988)), revealed a very strong influence of silvicultural treatment on the magnitude of growth stresses in Eucalyptus delegatensis. Trees grown at wide spacings as well as on soils of high site index exhibit reduced growth strain. A moderate thinning did not modify the growth strain but a heavy early thinning decreased it. Growth strain seems to be strongly related to the degree of competition between trees as indicated by stand basal area.

Sawmill studies found that the removal of the pith in the first cut will remove the zone of high longitudinal compression and radial tension, and will prevent splits forming in the remainder of the log. Sawing techniques are described by Haslett (1988). An example is illustrated in figure 2.8 below. This sawing pattern is suggested as appropriate for quarter sawing of Eucalypt logs under 43 cm in diameter. Cut 1 and cut 5 can release maximum stress on the pith.

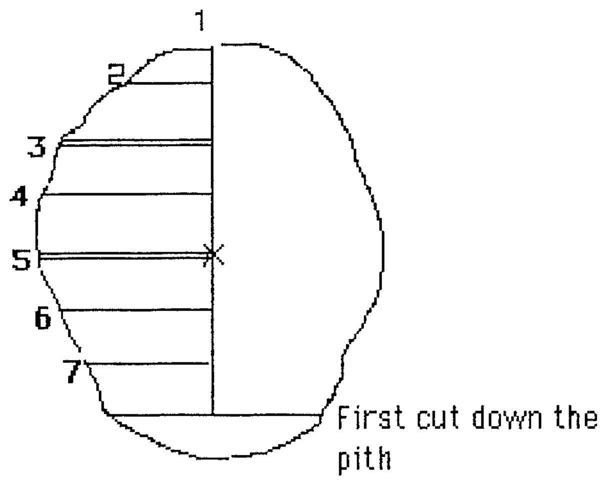


Figure 2.8 The sawing pattern suggested by Haslett (1988)

Note:

cut 1: along pith, subsequently saw half log on headrig cut 2: half taper cut approximately 100 mm from periphery

cut 3: sizing cut followed by straightening cut

cut 4: sizing cut to board thickness

cut 5: Release carriage central head dogs to release log stress held in by carriage heads, redog, then make straightening cut followed by a sizing cut.

cut 6: sizing cut

cut 7: sizing cut leaving 100 mm from edge.

(Source:Haslett, 1988)

Research on the Saw-Dry-Rip (SDR) method of manufacturing studs (Maeglin, 1979) showed that live sawing flitches of Aspen (Populus tremuloides) and drying them before ripping into studs resulted in substantial warp reduction as compared to conventionally manufactured studs. Flitches dried at high temperatures (above 100 degrees centigrade) resulted in an even greater reduction in warp.

The extra width of the flitches plus a somewhat better balanced stress distribution, restrains the tendency to warp while drying. In high temperature drying the lignin will become plastic and the stressed fibres slip past one another minimizing the stress. On cooling, the lignin again solidifies, holding the fibres in a relatively unstressed condition.

In order to determine the minimum temperature level that is effective for relieving the stress in timber Maeglin et al. (1985) conducted an investigation on the effect of high temperature drying and equalizing to relieve longitudinal growth stresses. Small diameter yellow poplar (Liriodendron tulipifera) logs were sawn into flitches to evaluate total stress levels in green flitches and final stress levels in dried flitches. The temperatures evaluated were 93 ^{o}C, 116 ^{o}C, 127 ^{o}C, and 143 ^{o}C. Equalizing times were 10, 20, 40 and 100 hours at 10% EMC. Results showed that the average stresses for centre flitches in the green condition were about 3.4 MPa. Average stresses were 1.3 MPa for all high temperature dried materials without equalizing, and 1 MPa for all equalized materials. It is clear that high temperature drying reduces the residual stresses and high temperature drying with equalizing provides even more stress relief. 10 hours equalizing is sufficient in high temperature drying, because there is no significant differences in the residual stresses between 10 hours equalizing and 20 hours or even 100 hours.

Nicholson (1975 b), in a study of the effect of storage on growth stress, stored logs both in the open and under water sprays. He found that a mean reduction (in the order of 20%) was observed following a storage time of approximately 300 days. It has been suggested that normal storage of timber or storage under water for a long period will reduce internal stress.

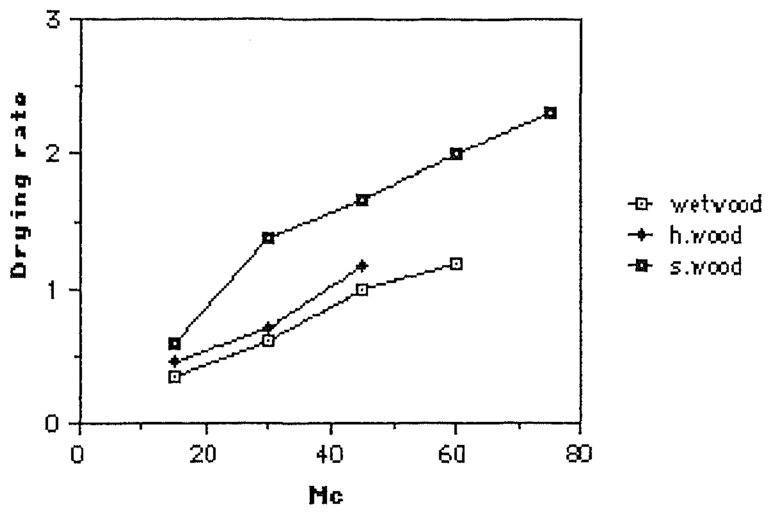
Also, wide use has been made of S-shaped hooks hammered into the cut surface of logs. This does not relieve the stresses, but it does keep the logs intact until partial drying increases the transverse tensile strength and balances some of the internal stresses. Dinwoodie (1966) stated that reduction in degrade and easier sawing can be achieved by the use of frame saws, or double edging saws. In these, the stress is equalized in the opposite sides of the log. Sawing alternate faces proves to be a poor substitute.

2.5.4.3 Wetwood

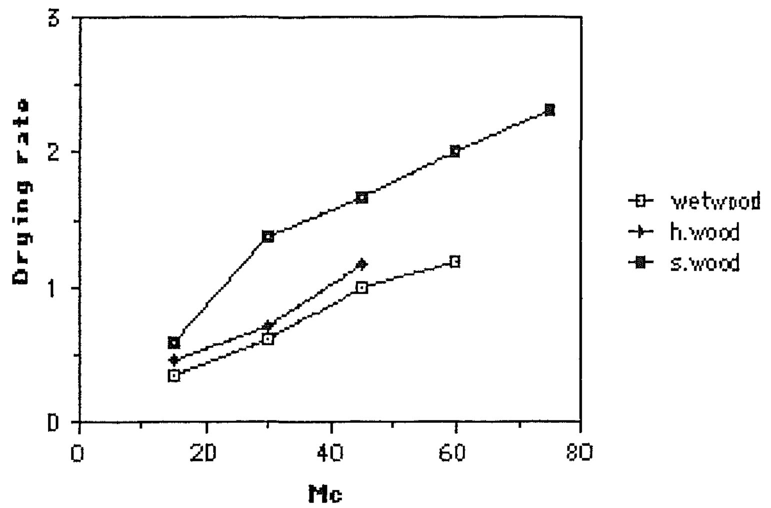
Wetwood in poplar is the term applied to the streaks or pockets particularly at the sapwood - heartwood interface, where moisture contents in the order of 150 to 200 %, while adjacent normal wood is 80 - 130 %.

During drying these areas are reported as being prone to collapse and ring shakes. Collapse can be expected in wetwood when the bonding strength between the cells has been weakened and the rate of internal moisture loss through the cell cavities is restricted.

Of more importance is their apparently low permeability which results in excessively wet zones remaining in kiln dried lumber (Mackay, 1974). This is confirmed by the result of the investigation of the effect of wetwood on drying rate of aspen (*Populus tremuloides* and *Populus grandidentata*) by Ward (1985). He recorded that wetwood board samples from both aspens took longer to dry to 15 % MC than did normal boards. The result of this investigation is illustrated in the diagram below (Figure 2.9)



A



B

Figure 2.9 The relationship between drying rate and moisture content by air drying (A) and Kiln drying (B).

2.6 Previous Work On Poplar

Because poplar is prone to warp during the drying process due to growth stress and other abnormalities in the wood, most investigations have been conducted to develop a method designed to reduce the effect of these abnormalities on the final quality of the dried wood. The investigations included: Saw Dry

Rip (SDR) method, using various drying schedules, to determine the relationship between internal conditions in the dry kiln and the occurrence of defects in wood.

Saw Dry Rip is wood processing beginning with live sawn through and through on the same plane, into flitches, Figure 2.10. The flitches are then roughly edged before kiln drying to conserve kiln spaces, and dried at conventional (below 95 ^{o}C) or high temperature drying (above 100 ^{o}C). After drying, the flitches are ripped into studs for maximum utilization (Maeglin, 1979).

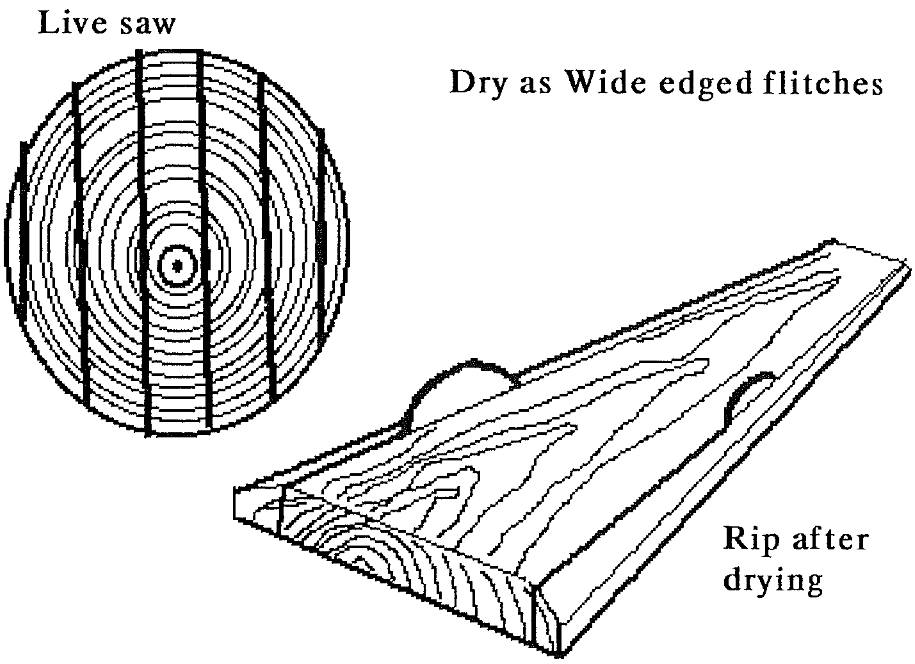


Figure 2.10 Steps in SDR process.

Because the large size flitches can restrain the stress due to their larger size combined with high temperature, it is assumed that warp can be reduced (Maeglin, 1979). This was proved by the results of his study on various dimensions of aspen which showed that SDR with high temperature drying produced less crook, less bow and less twist than conventionally sawn and dried studs. The result of evaluating the effects of saw dry rip both in conventional drying and high temperature drying by Huber et al. (1984) supported the result of Maeglin (1979) above. He suggested that SDR with conventional drying reduced crook and bow, whereas high temperature drying reduced twist as well.

The effect of temperature in relieving the stress in populus is also of interest to many researchers. Using Aspen, Bello (1976) concluded that elastic strain increased linearly with either increasing temperature or moisture content of the wood. From this study he suggested that to avoid surface checking, in the early stages of drying elevated humidity should be used to keep the surface of the wood fairly moist.

A detailed study evaluating the effect of wood drying schedules to the final quality of aspen was conducted by Huffman and Cech (1976). They evaluated conventional drying schedules, high temperature drying, low temperature drying and combination of schedules. For example low temperature drying prior to high temperature drying. They reported that high temperature drying reduced drying time by 40% but degrade was increased by 70% and the variation in final moisture content was increased. Low temperature drying prior to high temperature drying resulted in a marked decrease in final moisture content variation and 35% reduction in degrade, but it required a 50% increase in drying time. A combination schedule utilizing low conventional and high temperature drying resulted in least degrade. Value losses were reduced by 70% with no increase in drying time to final moisture content. However, variability remained a problem.

Another defect that was often found in poplar dried wood was collapse. It was shown that collapse in aspen was often related to the presence of wet wood. The combined effect of external factors (temperature and humidity) also had an effect on the time to collapse. Kemp (1959) found that temperature and humidity of 70 ^{o}F (21 ^{o}C) and 70% showed the greatest effect. He suggested that the two conditions had the greatest effect on the time to collapse.

III WOOD COLLECTION AND DATA

3.1 Wood Collection

This study explores the drying processes and options available to reduce the effects of tension wood and growth stresses in poplar of sawn timber quality. There were 4 main parts to the study. The first was to determine the physical characteristics of the wood in the trees that had been selected, the second part was the sawing of the logs into flitches and the determination of the drying characteristics, the third study involved the process of breaking down the dried flitches to the required dimensions and determining the quality of the final product. Finally the fourth section looked at the analysis of the effects of the treatments and the quality of final products.

The wood used in this study was Populus "androscoggin" the hybrid of Populus trichocarpa and Populus maximowiczii (Herpka, 1896). It was collected from the river-bed plantation near Timaru. This plantation was planted by the South Canterbury Catchment Board for erosion control and stopbank stability.

Thirty trees with an average diameter at breast height of 42 cm were selected by the SCCB as being broadly representative of the size and quality of available for milling from their woods. They were classified into two groups: straight (0 - 2^{o} lean) and leaning trees (2 - 10^{o}). Since tension wood is predominantly found on the upper-side of leaning trees (Kaeiser, 1955) the upper-sides of the trees were marked before felling.

After felling, 3 disks about 50 mm thick were cut from each tree. The first disk was cut from the stump (about 50 cm above ground height). Two 4.8 m logs were then cut and a disk taken from the middle cut and one from the top end of the log. All disks were coded and then wrapped in polythene bags. These disks will be used for identification of basic density, eccentricity and green moisture content of the tree.

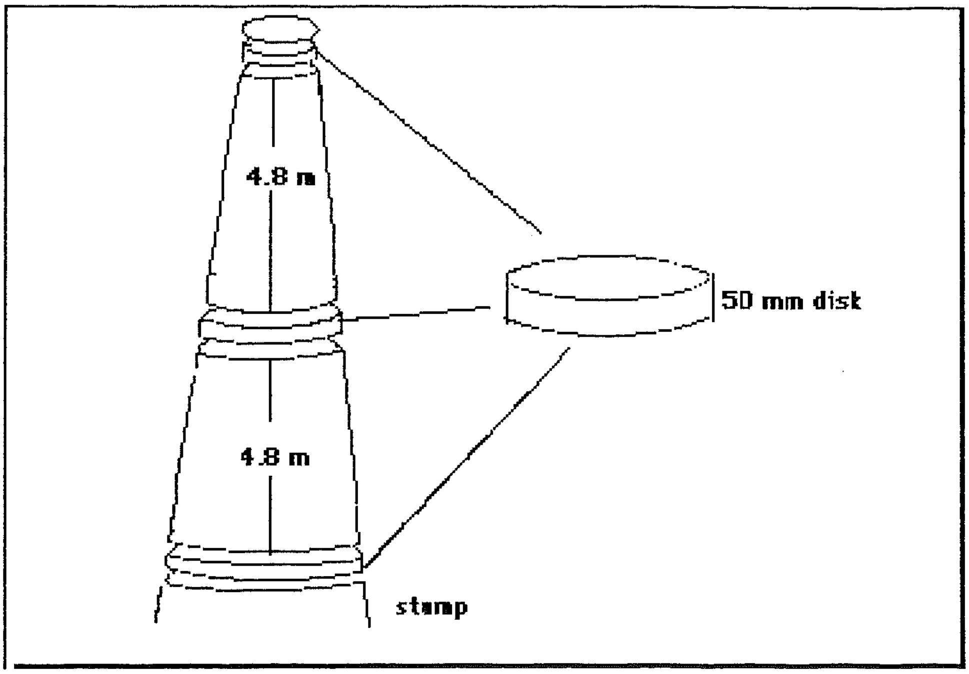


Figure 3.1 Disk and log position on the tree

All logs (4.8 m each) were coded to identify the type of tree (L(lean), S(straight)) and section of the tree (B(butt), T(top)). The 60 saw logs were then transported to Cook Brothers sawmill at Pleasant Point to be processed. The logs were broken down into flitches of 50 mm thickness. The logs were flat-sawn through and through after removing a small slab. This not only provided a flat surface so that the log lie flat on the saw "table" but also conserved the drying space in the kiln.

A circular saw headrig was used for cutting the logs into flitches, this was not ideal because it was hard to hold the log through the saw and cut accurately. Also we were unable to produce the maximum width of flitches when the larger logs were cut. In SDR methods the widest flitches are favoured since the wide flitches restrain stresses better than do narrow flitches.

The log was cut perpendicular to the mark on the tree as shown in Figure 3.2, so that boards were cut from either the upper-side of the lean (tension wood) or from the lower side of the bole.

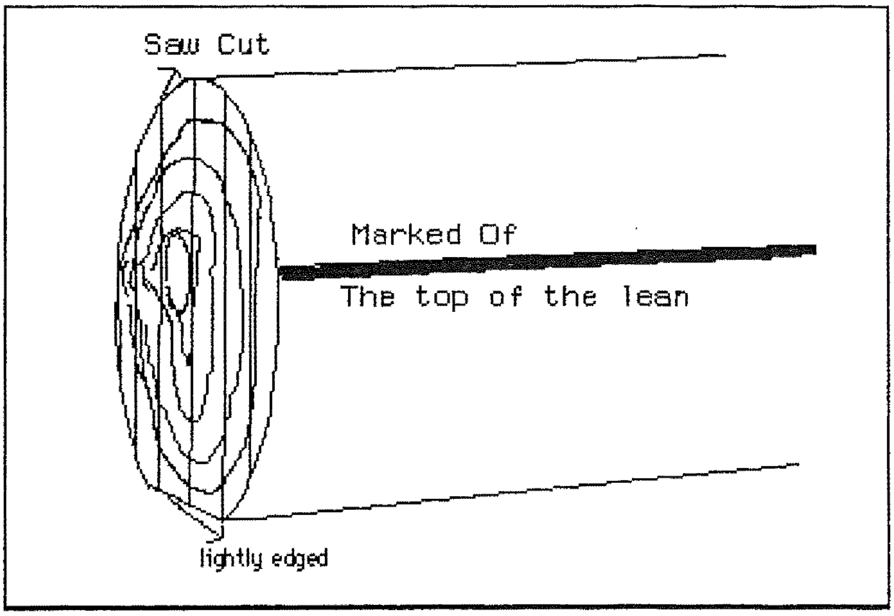


Figure 3.2 The sawing pattern of the logs

The boards were then numbered. The numbering system used recognized the type of tree (Leaning and straight) the section where the logs came from (butt log or top) finally followed by the sequence of the cut. Unfortunately the numbering system of the sequence of the cut did not take into consideration the position of the boards in respect to the mark (for example the sequence number one did not always indicate the boards closest to the mark). All of the boards then transported to the School of Forestry , University of Canterbury.

3.2 Data Collection and Analysis

3.2.1 Disks

3.2.1.1 Preparation and data collection

A total of 90 disks 50 mm thick were obtained from 30 trees. These were stored in cold room until measured. Each disk was then planed to enable the growth rings to be cleanly seen and counted. The major and minor diameters of the disk were measured to yield information on the eccentricity of the stem and growth rate. The diameter of the heartwood of each disk was also measured.

Three triangular pieces were cut from the disk. The position of each sample can be seen in Figure 3.3

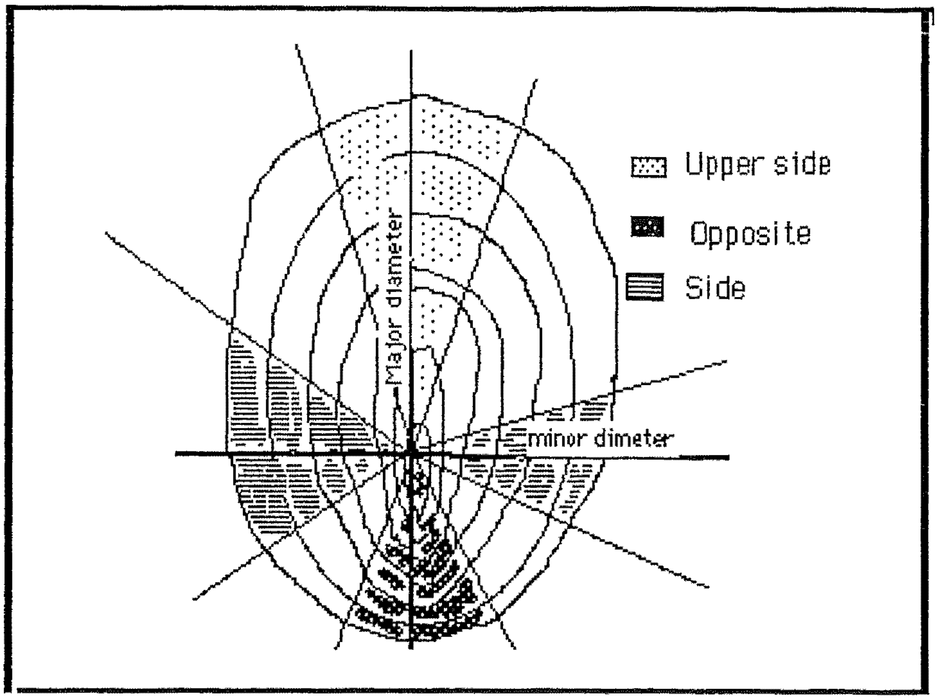


Figure 3.3 The position of the samples on the disks

The disks were coded: M denoted the upper-side of the lean (tension wood), O denoted the opposite and S denoted the side of the tree.

These 270 sectional disks were numbered and then weighed to determine their green weight. The green volume of the disks was measured by the water immersion method. The disks were then oven dried at 105 ^{o}C for 3 days. These measurements were used to determine the green density, basic density and green moisture content distribution within the tree.

3.2.1.2 Analysis

The moisture content was calculated by the formula:

$MC = ((GW-OD)/OD)\ 100\ \%$

and basic density was calculated from:

$BD = (OD)/(GV)$

whereas green density:

$GD = (GW)/(GV)$,

where: MC = Moisture content
GW = green weight
OD = oven dry weight
GV = Green volume
BD = Basic density
GD = Green density

Analysis of variance

Average basic density, green density and green moisture content and standard deviation for each treatment were determined for all logs.

An analysis of variance option (factorial) was used to determine significance variation of response between the means of section of the tree (bottom, middle, top), between the type of tree (leaning, straight) and between the direction in the tree ("mark", "opposite" and "side").

The statistical design of this experiment was a 2 x 3 x 3 factorial comparing:

2 factors of tree (leaning and straight)
3 factors of section (stump height, middle and top)
3 factors of directions ("mark", "opposite" and "side")

The model was:

$$Y = m + T_i + S_j + T_iS_j + D_k + T_iD_k + S_jD_k + T_iS_jD_k + e_{ijkl}$$

where, m = the general mean of the observation

T_i = effect of ith class of tree

S_j = effect of jth class of section

T_iS_j = effect of interaction between tree and section

D_k = effect of kth class of direction

T_iD_k = effect of interaction between tree and direction

S_jD_k = effect of interaction between section and direction

e_{ijkl} = a random variable.

If a single treatment indicates a significant difference, the least significant different analysis will be carried out to test potential significance in the response amongst all possible pairs of means. For example, if a section shows a significant difference, the least significant difference will be carried out to test the differences of the mean between:

- stump height vs. middle height
- stump height vs. top
- middle height vs. top.

All analyses were processed by SAS program at the University of Canterbury (Anonymous, 1985).

3.2.2 Logs

3.2.2.1 Preparation

After breaking down the logs into 240 flitches these were transported to the Forestry School. Here the boards were sprinkled with water to retain moisture before further processing. The boards were then cut into 2.4 m long boards and numbered.

The 480 flitches were then randomly allocated to one of six drying treatments. The six treatments were:

1 air drying

2 dehumidification in cool storage (1 ^{o}C)

3 low temperature drying (40 ^{o}C)

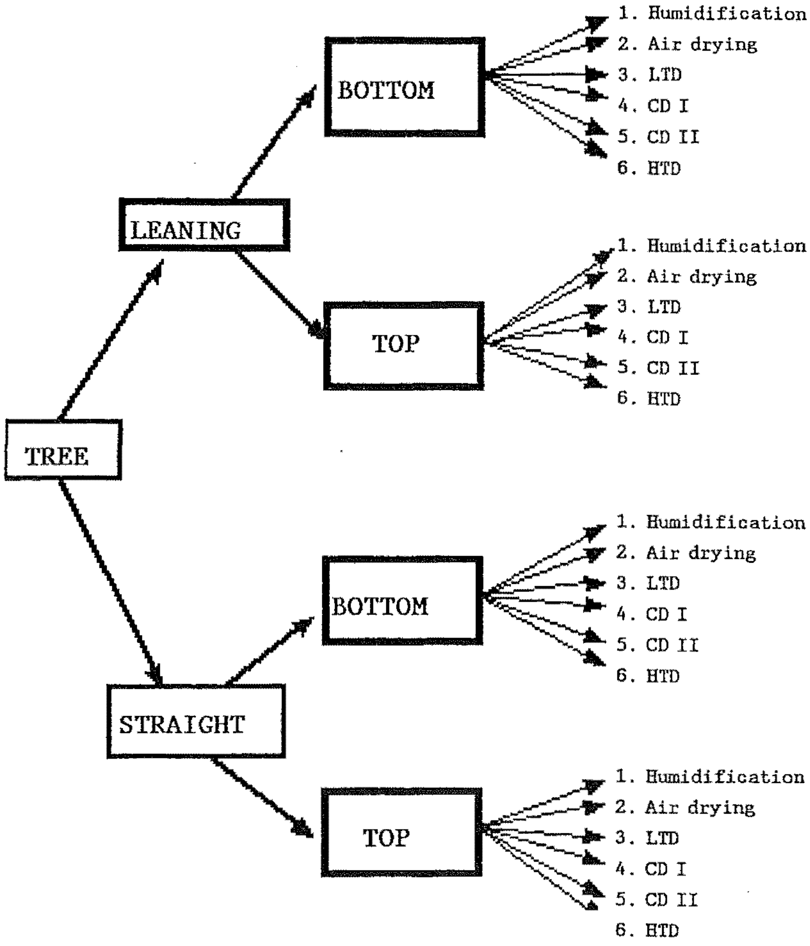
4 conventional drying I (60 ^{o}C)

5 conventional drying II (80 ^{o}C)

6 high temperature drying (above 100 ^{o}C)

The boards were block stacked into 6 groups. Each group was sprayed on the end of the pack with different colours. Five groups were transported to Coolpak storage, Prebbleton and stored at 1 ^{o}C and $\pm$ 90 % relative humidity. While in cool storage the boards were covered with black polythene.

The experimental design is shown below.



3.2.2.2 Drying Procedures

As mentioned, this study used six drying methods, namely air drying, dehumidification, low temperature drying, conventional drying I and II and finally high temperature drying.

3.2.2.2.1 Air drying

The 2.4 m flitches were cut to 2.1 meters and end coated with a 2 part epoxy resin and allowed to cure for 12 hours.

The boards were then weighed to determine the green weight and stacked for air drying beside the

Wood Science Laboratory, School Of Forestry. The stack of timber was raised above ground on 100 mm bearers. The dimension of stickers used for this study were 20 mm X 20 mm. The stickers were aligned vertically above each other over the bearers as viewed from the side of the stack. Four spare boards were placed on the top as a weather cover. The fluctuation of temperature and relative humidity during drying was recorded with a thermohygrograph placed on top of the stack.

To determine the loss of water each board was weighed every 6 weeks and re-stacked in reverse position (the boards from the top become the bottom and those from the bottom become the top).

3.2.2.2.2 Humidification

After weighing to determine initial weight a further 80 flitches were stacked as for air drying in the cool store. All boards were weighed and re-stacked every 2 months. The temperature inside the cool store was about 1 ^{o}C and the humidity was about 90 %.

3.2.2.2.3 Kiln drying

-Apparatus

The drying chamber used in this study was a laboratory unit kiln, with the capacity of 0.6 m^3 of boards. The kiln was provided with a digital control programmer (DCP 511) and Digital process reporter. In this type of kiln the entire schedule that was used was programmed into the digital control programmer before drying started. The kiln automatically shut down when all programs had been completed. Conditions during the drying process were recorded by a digital process reporter. The record included dry-bulb and wet-bulb temperature.

The source of dry heat was an electric element while the relative humidity was regulated by steam injection into a water-trough or by venting. The air circulation was distributed by 2 variable speed/reversible fans.

-Drying schedule

Four categories of schedule were used:-low temperature drying, conventional drying I, conventional drying II, and high temperature drying. Due to differences between the schedules used in respect to "severity", some differences in drying degrade could not be avoided.

Time based drying schedules derived from existing drying schedules of Populus used by other researchers in their investigations, were adapted for this study. The drying schedules used for this study were from Boone (1984), Huffman and Cech (1976), Rasmussen (1961), Pratt (1974) and Wengert (1974).

The complete drying schedules are presented in Table 2.1.

Table 2.1. The drying schedules for low temperature drying, conventional drying I, conventional drying II and high temperature drying.

LOW TEMPERATURE DRYING

DBT (°C)	WBT (°C)	RH (%)	EMC (%)	TIME (DAYS)
40	37.5	85	15	1
40	35	70	14	1
50	37.5	44	7.5	3
50	35	37	6.5	10
50	45	75	14	0.25
			TOTAL	15.25

CONVENTIONAL DRYING I.

DBT (°C)	WBT (°C)	RH (%)	EMC (%)	Time (days)
60	57.5	87	15.8	3
60	55	77	12.5	1
70	60	63	8.6	2
70	55	47	6.4	4.75
75	70	80	11.8	0.25
			Total	11

CONVENTIONAL DRYING II

DBT (°C)	WBT (°C)	RH (%)	EMC (%)	TIME (Days)
80	77.5	91	15.8	2
80	75	77	10.6	1
90	80	60	7	1
90	75	53	6	3.75
90	85	82	11.3	0.25
			TOTAL	8

HIGH TEMPERATURE DRYING

DBT (°C)	WBT (°C)	RH (%)	EMC (%)	TIME (HOURS)
70	65	79	12.1	0.5
			RAMP	(0.5)
100	95	83	11	2
105	100	84	10.7	4
110	100	70	6.9	5
			RAM	(1)
115	70	19	1.7	17
95	90	82	11.2	6
			TOTAL	36

- Kiln charges and stack configuration

Prior to drying, the boards for that trial were marked with a straight line along the middle of the board and weighed to the nearest 0.1 kg. The weights of the boards were determined after end coating with epoxy resin. In this experiment the weight of epoxy resin coating was ignored, because the coating weight was small compared to the board weight, and had no appreciable effect on the computed water loss during drying. Four boards (1 from each treatment of tree type) were selected randomly for measuring the thickness and the width before drying. Also the ends of the boards were inspected for checks and any defects recorded.

The boards from each treatment of the tree (leaning bottom, leaning top, straight bottom and straight top) were randomly stacked on 18 mm thick stickers spaced 50 cm apart forming a stack about 0.9 m height, 0.7 m width and 2.1 m long. At one end of the stack a box was used as a baffle to ensure the air circulation was through the pile and to provide access to the interior of the kiln if needed. The air pressure for restraint the top of the load was about 480 kPa. The average of air speed through the load was 3.5 m/sec for conventional drying I and 5.0 m/sec for the other drying schedules (in all drying schedules the fans reversed every 6 hours). The air velocity through the stack was measured with an anemometer before the actual schedule started.

3.2.2.3 Measurement after drying

The kiln remained closed for approximately 6 hours to cool. The boards were then weighed and final moisture contents estimated using a power loss type moisture meter (Wagner, model L 600). The thickness and the width of the selected boards were also measured. Finally the measurement of defects especially end-check, crook, bow and twist were recorded. Crook is deviation towards an edge from a straight line drawn from end to end in the middle of the boards. The measurement of crook is illustrated in Figure 3.4 below (Crook is defined in terms of both the reading a and the length of the board).

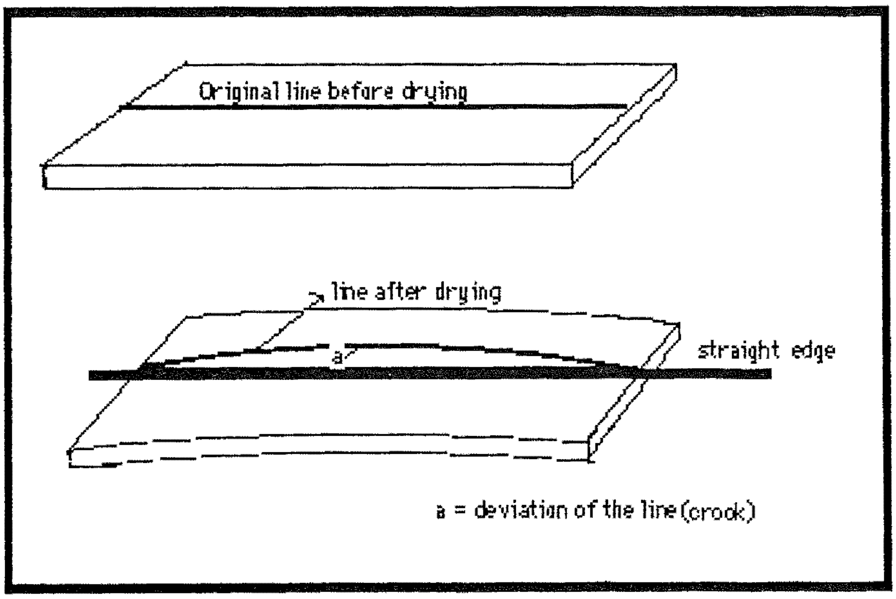


Figure 3.4 Measurement of crook

- Processing after drying

5 samples from each treatment (5 x 2 x 2 x 4 = 80 samples) were selected randomly and taken from production to evaluate the effect of the treatment

on the final product. The final product was shook for asparagus containers, so the boards were cut accordingly. The 80 sub-samples were ripped to 100 mm wide and cut into 1 m lengths. Finally the boards were multi-sawed to 6mm thickness. The final size of the boards was 1000 x 100 x 6 mm. The final processing of sub-samples of wood can be seen in Figure 3.5.

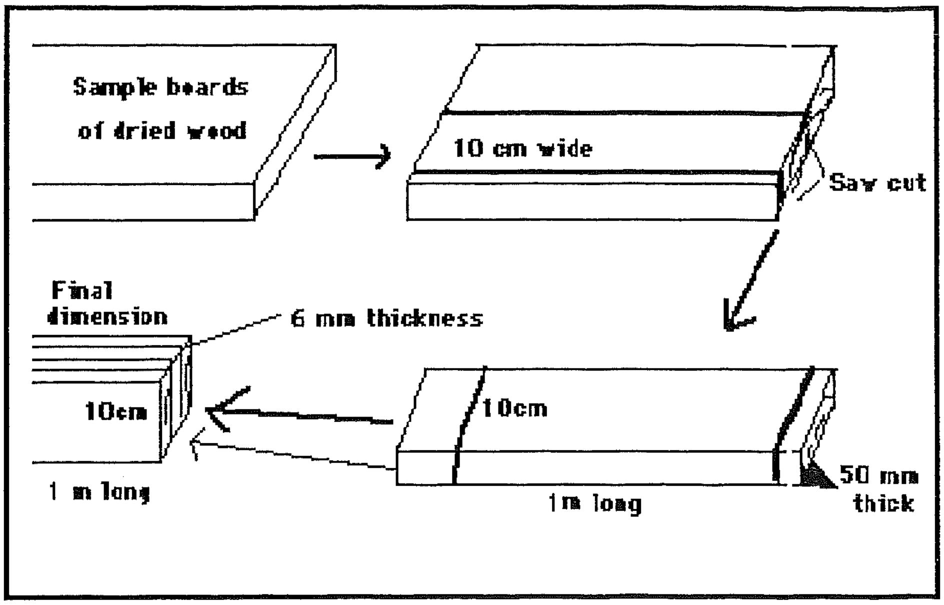


Figure 3.5 Final processing of sample boards

The quality of each sub-sample including the deformation of the boards were recorded.

3.2.2.4 Analysis

Based on the relationship of final moisture content estimation and final weight of sample boards, the moisture loss due to drying was calculated.

The initial moisture content can be obtained by:

IMC = (((GW-100 KDW)/(100+FMC))/((100 KDW/(100 + FMC))),

where: IMC = initial moisture content

GW = green weight

KDW = kiln dry weight

FMC = final moisture content

The rate of drying can be estimated from the moisture content loss and the time needed to dry the wood.

Analysis of variance

The statistical design of this experiment was a 2 x 2 x 4 factorial comparing:

2 factors of tree (leaning and straight)
2 factors of section (bottom and top)
4 factors of drying methods

The model was:

$$Y = m + T_i + S_j + T_iS_j + D_k + T_iD_k + S_jD_k + T_iS_jD_k + e_{ijkl}$$

where, m = the general mean of the observation

T_i = effect of ith class of tree

S_j = effect of jth class of section

T_iS_j = effect of interaction between tree and section

D_k = effect of kth class of drying method

T_iD_k = effect of interaction between tree and drying method

S_jD_k = effect of interaction between section and drying method

e_{ijkl} = a random variable.

The principle criterion for evaluation was warp and drying rate. The criteria for warp were as for the National grading rules: NZS :3631 (Standard Association of NZ, 1988).

Least significant difference test was used to contrast variable classes in order to determine the effect of the treatment to the final products.

All the processing in analysis of variance were processed by SAS, University of Canterbury.

IV. RESULTS OF DISK ANALYSIS

4.1 General characteristics of the trees selected

4.1.1 Diameter over bark and under bark

All diameters over bark and under bark are presented in Appendix 1. A summary of the average and its standard error of the diameter for the type of tree and the location in the tree are presented in Table 4.1.

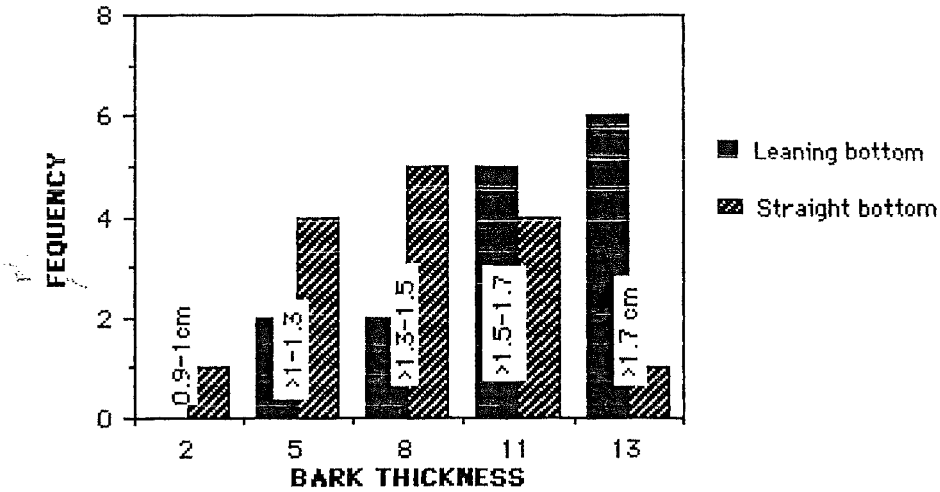
Table 4.1 The diameter over bark and under bark of the tree selected at different location of disk.

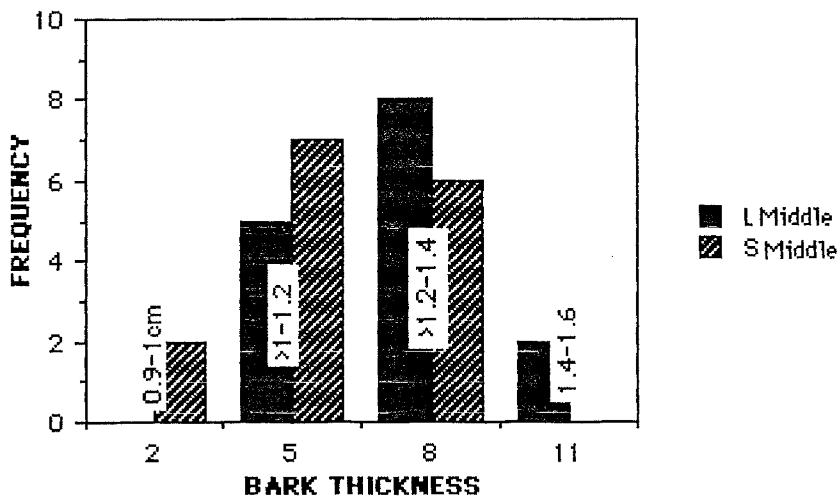
Tree	Section	DOB (cm)	DUB (cm)
Leaning	Bottom	46.99	45.31
		(3.77)*	(3.66)*
	Middle	35.31	34.07
		(3.34)*	(3.26)*
	Top	28.04	27.00
		(2.75)*	(2.74)*
Straight	Bottom	47.03	45.66
		(4.44)*	(4.37)*
	Middle	36.00	34.84
		(2.96)*	(2.87)*
	Top	31.20	30.16
		(2.84)*	(2.83)*

Note *) denoted standard deviation

The average bark thickness at the stump height was 1.55 cm with a standard deviation of 0.33. The average bark thickness at the middle (4.8 m up from the stump height) was 1.20 cm with a standard deviation of 0.19, whereas the average thickness on the top of the tree was 1.04, ranging from 0.4 to 1.4 cm. The distribution frequency of bark thickness between and within the tree is illustrated in Figure 4.1.

The distribution frequency in this report define as the number of frequency of boards or disks in the class of response (e.g. range of moisture content) within the population of disks or boards examined.





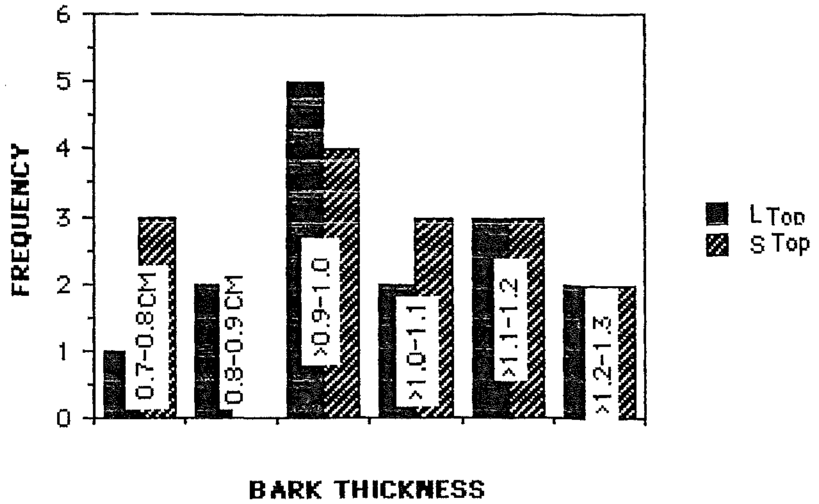


Figure 4.1 The distribution frequency of bark thickness between and within the tree.

A linear regression analysis to determine the relationship between the diameter over bark and the thickness of the bark was carried out and the result is presented in Table 4.2 The scatter diagram for this relationship can be seen in Figure 4.2.

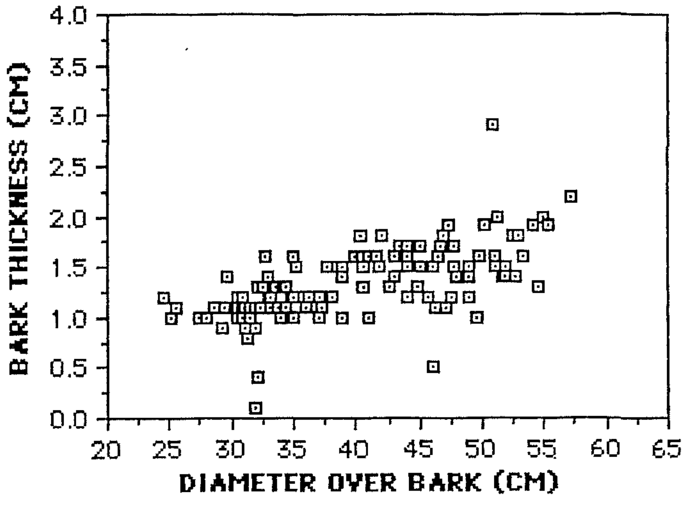


Figure 4.2 Scatter diagram of the relationship between bark thickness and diameter over bark

Table 4.2 Parameter estimate of the relationship between bark thickness and diameter over bark

Variable	DF	Parameter estimate	Standard error	T	P>T
Intercept	1	0.25	0.0875	2.81	0.0055***
DOB	1	0.027	0.0023	11.86	0.0001***

Note: Significant at level 1 %

The result shows that there is a positive relationship between the diameter over bark and the bark thickness, with the equation:

BT = 0.25 + 0.027 DOB
where, BT = bark thickness (cm)
dob = diameter over bark (cm).
Coefficient of correlation (r) = 0.66

The mean number of annual rings in the leaning tree at the bottom, middle and top were 16, 14 and 12, respectively. Whereas the annual ring in straight tree from the bottom to the top were 17, 15 and 13 respectively. The average of growth ring (width) in each type of tree and in each section is presented in Table 4.3.

Table 4.3 The average growth ring width between and within the tree (cm)

Tree	Section		
	Bottom	Middle	Top
Leaning	2.78 (0.24)	2.45 (0.21)	2.31 (0.23)
Straight	2.73 (0.23)	2.36 (0.21)	2.31 (0.21)

Note: the value in the bracket is standard deviation

The block analysis of variance was carried out to determine the differences between the type and the position in the tree. Since the leaning tree grown in different block from straight tree , this type of tree can be regarded as one block and the section as the treatment. Table 4.4 shows the result of this analysis.

Table 4.4 Analysis of variance of growth rings.

Source	DF	SS	MS	F	P>T
Tree	1	0.3712	0.3712	1.00	0.3201
Section	2	4.7590	2.3795	6.41	0.0025***
Error	86	31.9212	0.3712		
Total	89	37.0514			

Note: ***) significant at level 1%

Table 4.4 shows that there is no significant different between the width of the growth ring of straight tree and leaning trees, whereas the section showed some difference. From LSD analysis can be seen that the differences occur between Bottom and Middle, Bottom and Top discs. There is no significant difference between growth rings at the middle and at the top.

4.1.2 Sapwood and heartwood

The diameter of heartwood and its ratio to diameter under bark in all trees and at all sections of disk are presented in Appendix 1. The summary of the average of heartwood diameter is presented in Table 4.5.

Table 4.5 The average heartwood diameter between and within the tree

Tree	Section		
	Bottom	Middle	Top
Leaning	31.0 (5.2)	23.1 (6.5)	14.0 (2.4)
Straight	33.5 (3.9)	23.9 (3.4)	17.8 (3.1)

Note: The value in the brackets represent standard deviation

The average of the heartwood ratio to the diameter under bark were: 0.71, 0.66 and 0.52 respectively for the bottom, middle and top discs of leaning tree. Whereas the ratio at the bottom, middle and top of the straight trees was 0.72, 0.68 and 0.59, respectively. Nelson (1976) in a study of the relationship between diameter under bark and diameter of heartwood in black walnut found a positive relationship with high coefficient of correlation.

The scatter diagram of the relationship between diameter under bark and diameter of heartwood from data obtained in this study is presented in figure 4.3.

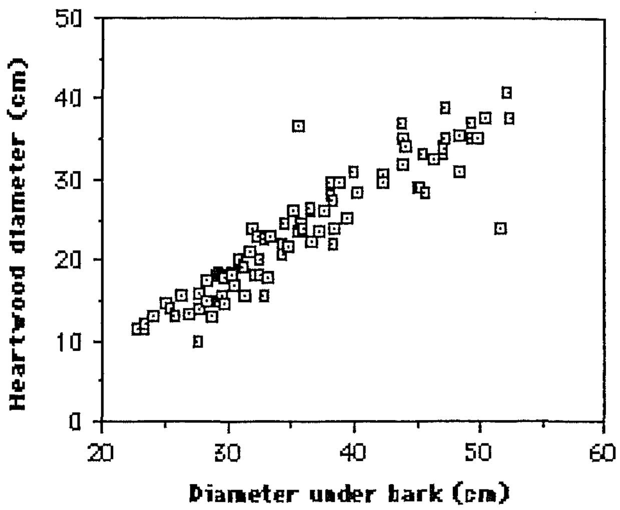


Figure 4.3 Scatter diagram of the relationship between heartwood diameter and diameter under bark.

From figure 4.3 it is clear that the results of this study agree with the results of the investigation by Nelson (1976). However, the data were obtained at different heights in the tree, so there is the possibility that the position of the disc up the tree influences this relationship.

A multiple linear regression was carried out to determine whether the height up the tree was influencing the diameter of heartwood.

The model equation used is :

$$Y = a + b X_1 + c X_2$$

Where Y = Heartwood diameter (cm)
X_1 = diameter under bark (cm)
X_2 = height of the disk in the tree (m)

The parameter estimate of the equation and its standard error is presented in Table 4.6.

Table 4.6 The parameter estimate in multiple regression of the relationship between heartwood diameter vs. diameter under bark and the height of the tree.

Variable	df	Parameter estimate	Standard error	Prob>T
Intercept	1	-2.0249	4.1478	0.6267NS
DOB	1	0.7444	0.0878	0.0001***
HT	1	-0.3567	0.1749	0.0445*

Note : NS = not significant
*** = significant at level 0.1 %
* = significant at level 5 %

Table 4.6 shows that the intercept obtained from the calculation did not differ significantly from null (0), so the intercept term should be dropped. The equation becomes :

$$Y = b X_1 + c X_2$$

The result of the estimation of each parameter is presented in Table 4.7.

Table 4.7 The parameter estimate of the equation of the relationship between heartwood diameter vs. diameter under bark and height without intercept.

Variable	df	Parameter estimate	Standard error	Prob>T
DOB	1	0.7019	0.0112	0.0001***
HT	1	-0.4362	0.0639	0.001**

Note : *** denotes highly significant (0.1%)
** denotes significance at level 1 %

The coefficient of correlation of this equation (r) = 0.99. It means that 99 % of heartwood diameter is associated with diameter under bark and the height of the disk in the tree. The equation is:

HW = 0.7019 DOB - 0.4362 HT.

4.1.3 Eccentricity

The eccentricity of the disk can be used as an indicator of the presence of tension wood. In this study the eccentricity is defined as the ratio of the major diameter to the minor diameter.

All values of eccentricity of the tree at stump height, in the middle and above the top log are presented in Appendix 1. A summary of the average for each type of tree and section is presented in Table 4.8.

Table 4.8 The eccentricity of the tree at different heights.

Tree	Section	Ecc.	StDev.
Leaning	Bottom	1.13	0.07
	Middle	1.15	0.12
	Top	1.09	0.06
Straight	Bottom	1.08	0.05
	Middle	1.06	0.04
	Top	1.04	0.03

The block analysis of variance was conducted to determine the difference in eccentricity between leaning and straight and also between the sections in the tree. The result of the analysis is presented in Table 4.9.

Table 4.9 The analysis of variance of the eccentricity.

Source	DF	SS	MS	F	P>T
Tree	1	0.0810	0.0810	15.5	0.0002***
Section	2	0.0274	0.0137	2.62	0.078
Error	86	0.4497	0.0052		
Total	89	0.5581			

Note:*** indicates significance at level 0.1 %.

Table 4.9 shows that significant differences (at level 0.1 %) occur between the eccentricity in leaning trees vs. the eccentricity of straight trees. In this case the eccentricity of leaning trees was greater than the eccentricity of the straight trees.

The difference between the sections (discs) was significant at the 10% level, and least significant difference (LSD) analysis shows that the eccentricity of the bottom of the tree was significantly different from the top of the tree.

4.2 Physical properties

4.2.1 Moisture content

All values of moisture content in this study are presented in Appendix 2. A summary of the average for each treatment is presented in Table 4.10.

Table 4.10 The average moisture content between and within trees.

Tree	Section	Direction		
		M	O	S
Leaning	Bottom	150.6	134.8	140.7
		(34.5)	(17.0)	(15.4)
	Middle	134.5	123.7	130.1
		(11.5)	(15.8)	(14.1)
	Top	113.1	108.5	115.0
		(11.4)	(12.3)	(10.9)
Straight	Bottom	146.9	150.7	153.2
		(32.7)	(10.5)	(10.8)
	Middle	134.5	136.8	137.3
		(11.5)	(11.7)	(12.8)
	Top	113.1	117.3	118.4
		(11.4)	(10.1)	(12.1)

Note: The value in the brackets is the standard deviation.

4.2.1.1 Variation between trees

The average green moisture content of individual trees in leaning trees ranged from 109 to 138 % and the average of all leaning trees was 126 %. The average of straight trees was slightly greater than that in leaning trees. The average moisture content was 135 %, ranging from 119 to 146 %. The variation of moisture content between trees is presented in Figure 4.4

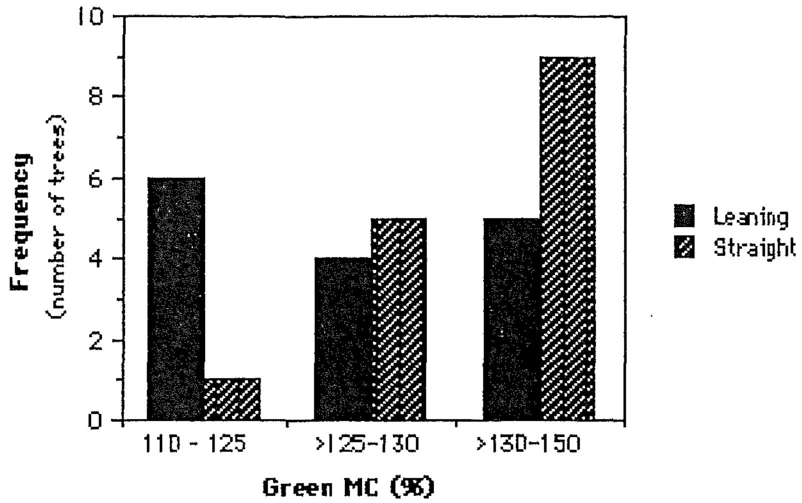


Figure 4.4 Distribution frequency of green moisture content between the trees.

4.2.1.2 Variation within trees

Table 10. clearly indicates a trend of decreasing green moisture content from the butt to the top of the tree. The moisture content also differs according to whether the one is sampling tension wood (uppermost side of the leaning stem) or elsewhere in the section.

The green moisture content of the bottom, middle and top ranged from 108 % to 83 %, from 102 % to 153 % and from 95 % to 136 %, respectively. The distribution frequency of green moisture content between the section of the tree can be seen in Figure 4.5.

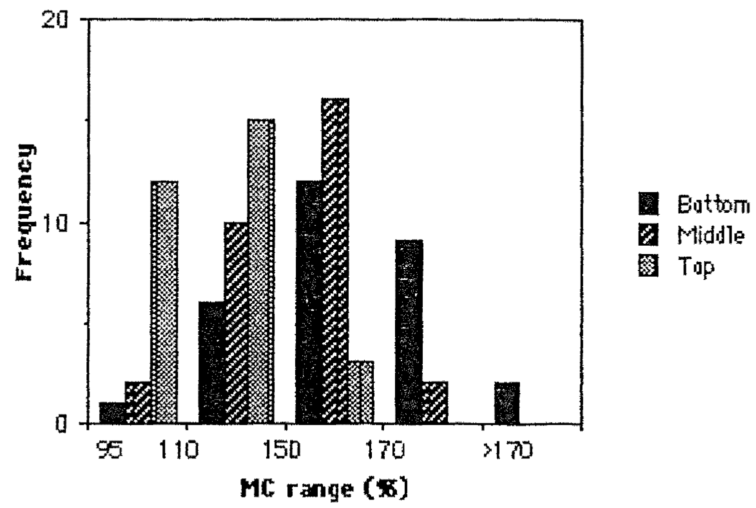


Figure 4.5 Distribution frequency of green moisture content between the section within the tree.

The green moisture content of "mark" (upperside) varied between 106 % to 152 %, whereas "opposite" and "side" direction varied between 98.4 % to 147.8 % and between 107.3 to 143.3 %, respectively.

An analysis of variance to determine the significant differences between the leaning trees and straight trees and within the tree was carried out, and the results are presented in Table 4.11

Table 4.11 The analysis of variance of green moisture content.

Source	DF	SS	MS	F	P>T
T	1	5402.52	5402.52	24.4	0.0001***
S	2	39748.81	19874.4	89.7	0.0001***
D	2	765.8771	382.9	1.73	0.18
T*S	2	1353.07	676.5	3.05	0.05*
T*D	2	420.1124	210.06	0.95	0.39
D*S	4	14.5758	3.6439	0.02	0.995
T*D*S	4	208.2702	52.0676	0.23	0.92
Error	251	55614.34	221.571		
Total	268	103527.58			

Note: T denoted tree
D denoted direction
S denoted section
***)Significant at level 0.1 %
*) Significant at level 5 %

The results of the analysis of variance show that there is a significant difference between the type of the tree (leaning vs. straight) at level 0.1 %. The section (the mean moisture content height up the tree) also indicates a statistically significant difference at level 0.1 %. Whereas the direction did not show a significant differences.

The interaction between the treatment did not indicate a significant difference, except to show the interaction between tree and section which was significant at level 5 %.

A least significant difference (LSD) analysis was conducted to determine further information of differences between the section. The result showed that the significant differences exist between all sections. Green moisture content of the bottom of the tree was significantly different from the middle and the top, also the green moisture content of the middle was different from the top. All the differences were significant at level 5 %.

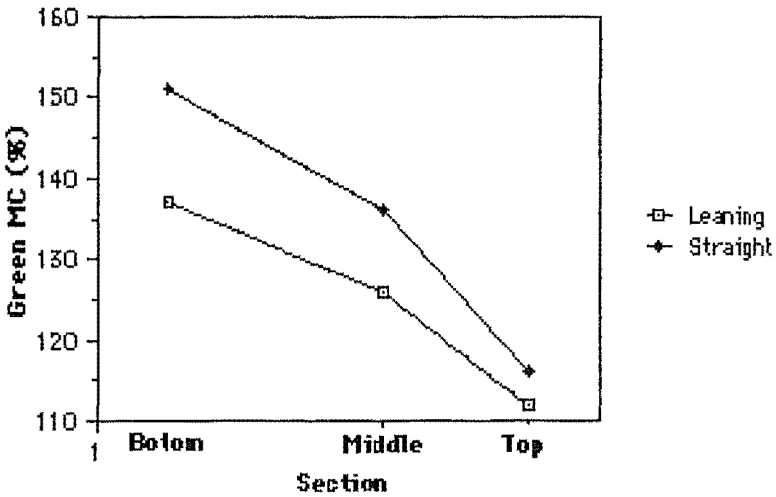


Figure 4.6 The average of green moisture content in leaning and straight tree at the bottom middle and top of the tree.

4.2.1.3 The relationship of green moisture content and heartwood proportion

A scatter diagram showing the relationship between the green moisture content and the percentage of heartwood to diameter under bark is presented in Figure 4.7.

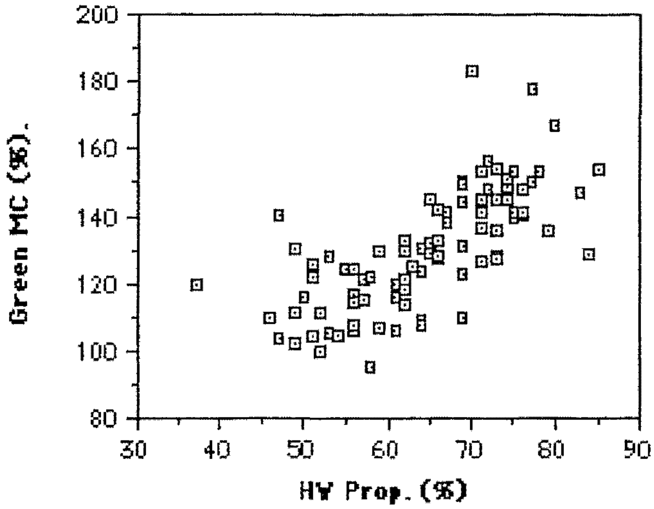


Figure 4.7 Scatter diagram of the relationship between heartwood proportion (%) and green moisture content.

A linear regression analysis was carried out to determine the significant effect of heartwood proportion to the green moisture content of the tree.

The model of linear regression is:

$$Y = a X + b$$

Where Y = Green moisture content (%)

X = Heartwood proportion (%)

a and b slope and intercept of the equation.

The estimated value of the parameter is presented in Table 4.12.

Table 4.12. Parameter estimate of the linear regression of the relationship between green moisture content and heartwood proportion.

Variable	DF	Parameter estimate	Standard error	P>T
Intercept	1	50.3	8.98	0.0001
Slope	1	1.24	0.14	0.001

The equation fits to the data:

Y = 50.34 +1.24 X., with the coefficient of correlation = 0.70.

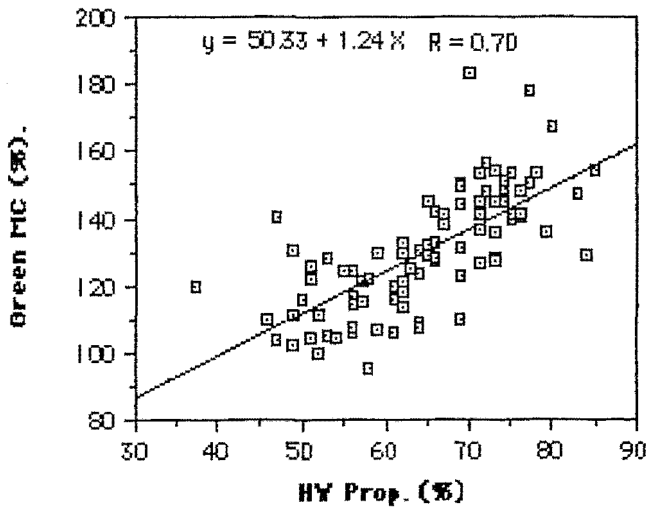


Figure 4.8 The relationship of green moisture content and heartwood proportion.

It is evident from the equation that the green moisture content of the wood in this study was positively correlated with the proportion of heartwood. This means that the greater the proportion of heartwood or the smaller the proportion of sapwood, the greater the moisture content. This can be confirmed by the result of the investigation by Yazawa (1965) quoted from Bamber (1985) who found that heartwood had a higher moisture content than sapwood in <u>Populus maximowiczii</u>. Unfortunately this study did not determine the moisture content of the sapwood and heartwood separately.

4.2.2 Green Density

All values of green density are presented in Appendix 2. and summarized in Table 4.13.

Table 4.13 The average of green density (gr/cm^3) between and within the trees

Tree	Section	Direction		
		M	O	S
Leaning	Bottom	0.841 (0.051)	0.843 (0.058)	0.834 (0.0620
	Middle	0.826 (0.063)	0.833 (0.081)	0.824 (0.059)
	Top	0.804 (0.051)	0.808 (0.047)	0.811 (0.046)
Straight	Bottom	0.823 (0.100)	0.819 (0.032)	0.827 (0.039)
	Middle	0.819 (0.065)	0.806 (0.034)	0.816 (0.036)
	Top	0.800 (0.051)	0.819 (0.065)	0.809 (0.053)

Note: The value in brackets is the value of standard deviation.

4.2.2.1 Variation between trees

The green density in leaning tree varied between 0.752 to 0.921 gr/cm^3 with the average of 0.825 gr/cm^3. Whereas the green density of straight tree varied between 0.787 to 0.869 gr/cm^3 with the average of 0.816 gr/cm^3.

4.2.2.2 Variation within the tree

A similar pattern of decreasing value to that for green moisture content from the butt up to the top of the tree occur in green density. The green density of the bottom of the tree varied from 0.745 to 0.909 gr/cm^3 with the average of 0.831 gr/cm^3, the average of green density at the middle of the tree became 0.821 gr/cm^3 or in the range of 0.706 to 0.983 gr/cm^3 The green density at the top of the tree varied from 0.751 to 0.788 gr/cm^3.

The direction also showed variation in green density. The green density of "mark" (upperside) direction, "opposite" direction and "side" direction varied from 0.715 to 0.921 gr/cm^3, from 0.75 to 0.97 gr/cm^3 and from 0.756 to 0.896 gr/cm^3, respectively.

A similar analysis of variance to that for green moisture content was made for green density analysis and the result showed in Table 4.14.

Table 4.14 The analysis of variance of green density

Source	DF	SS	MS	F	P>T
T	1	0.0057	0.0057	1.72	0.19
S	2	0.0225	0.0113	3.78	0.03
D	2	0.0005	0.0002	0.07	0.93
S*D	4	0.0022	0.0005	0.17	0.95
T*S	2	0.0049	0.0025	0.74	0.48
T*D	2	0.0005	0.0002	0.07	0.93
T*S*D	4	0.0039	0.0009	0.29	0.88
Error	251	0.8375	0.0033		
Total	268	0.8777			

Note: T = Type of tree
S = section
D = direction

The results show that there was no significant difference in the green density between the leaning trees and straight trees. There was also no significant difference in the green density between the directions of the tree.

The only significant differences were shown by the section of the tree (significant at level 5 %). LSD analysis revealed that the difference in green density between the bottom and the middle was not significant and also between the middle and the top. The only significant difference was shown between the bottom and the top.

4.2.3 Basic density

4.2.3.1 Basic density of leaning tree

A summary of the average basic density in leaning trees is presented in Table 4.15.

Table 4.15 The average basic density (gr/cm^3) in leaning trees.

Section	Direction		
	M	O	S
Bottom	0.357 (0.019)	0.360 (0.022)	0.347 (0.012)
Middle	0.366 (0.028)	0.373 (0.023)	0.359 (0.019)
Top	0.374 (0.020)	0.389 (0.035)	0.378 (0.023)

The basic density at the bottom of leaning tree varied from 0.32 to 0.38 gr/cm^3. The basic density gradually increased up the tree, at the middle of the tree the basic density varied from 0.34 to 0.41 gr/cm^3. At the top of the tree the basic density was in the range of 0.36 to 0.43 gr/cm^3. Figure 4.9 shows the distribution frequency of basic density in the section of the tree.

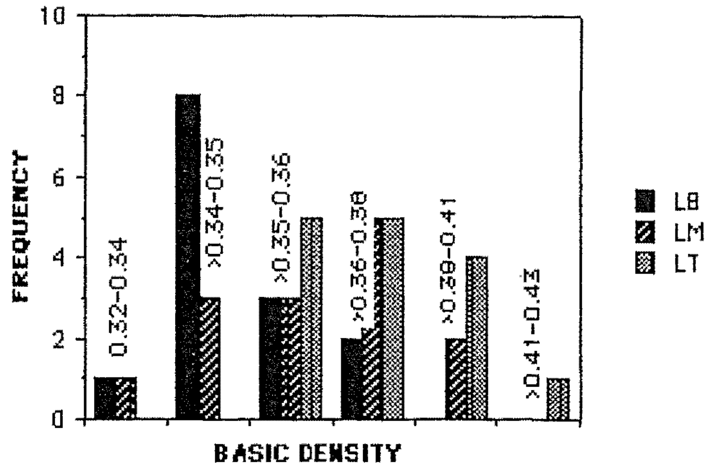


Figure 4.9 The distribution frequency of basic density between the section within the leaning tree.

The direction of the tree also showed a large variation of basic density. The basic density in the "mark" (upperside) direction varied from 0.33 to 0.40 gr/cm^3, the "opposite" direction varied from 0.35 to 0.42 gr/cm^3 and "side" direction varied from 0.34 to 0.37 gr/cm^3 The distribution frequency of basic density in the direction of the tree is depicted in Figure 4.10.

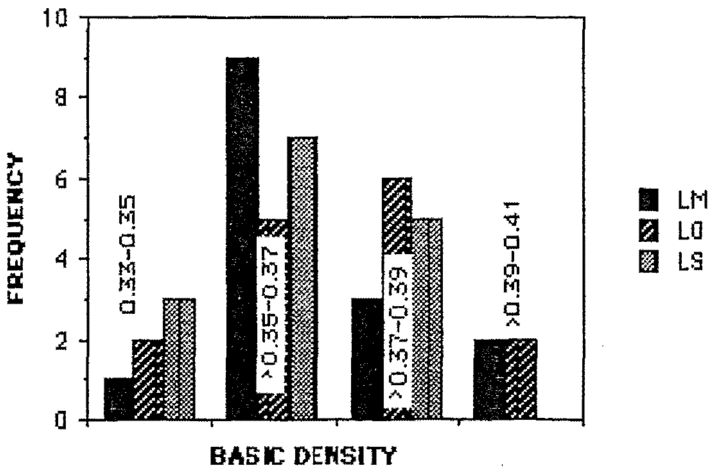


Figure 4.10 The distribution frequency of basic density between the direction within the leaning tree.

A block analysis of variance was carried out to determine the significant differences between and within the trees. Table 4.16 Show the result of analysis of variance.

Table 4.16 Analysis of variance of basic density in leaning trees

Source	DF	SS	MS	F	P>T
Section	2	0.01504	0.007521	4.19	0.0001***
Direct.	2	0.00370	0.001850	3.49	0.0334**
Error	130	0.06889	0.000530		
Total	134	0.08763			

Note: ***) Significance at level 0.1 %
**) Significance at level 5 %

The table shows that the basic density is significantly different at level 0.1 % between the sections. Least significant difference analysis indicates that all levels of section differ significantly: The basic density at the bottom (0.354 gr/cm^3) differs significantly from the basic density of the middle (0.365 gr/cm^3), and differs from the top (0.380 gr/cm^3).

The direction also showed significant differences at level 5 %. From least significant difference analysis it is clear that the only significant differences occur between the side and the opposite. There is no significant different between the "mark" (upperside) direction (0.365 gr/cm^3) vs. "opposite" (0.373 gr/cm^3), and also no significant difference between "mark" direction and "side" direction (0.361 gr/cm^3).

4.2.3.2 Basic density of straight trees

All values of basic density in straight trees can be found in Appendix 2. The summary of average basic density for sections and directions is presented in Table 4.17.

Table 4.17 The average basic density (gr/cm^3) in straight trees

Section	Direction		
	M	O	S
Bottom	0.330 (0.024)	0.327 0.008)	0.327 (0.011)
Middle	0.350 (0.029)	0.341 (0.008)	0.344 (0.015)
Top	0.376 (0.022)	0.377 (0.032)	0.371 (0.017)

The pattern of basic density in straight trees follows the pattern in leaning trees, where the basic density gradually increases from the stump height to the top of the tree. Figure 4.11 shows the distribution frequency of basic density at the bottom, middle and top of the straight trees.

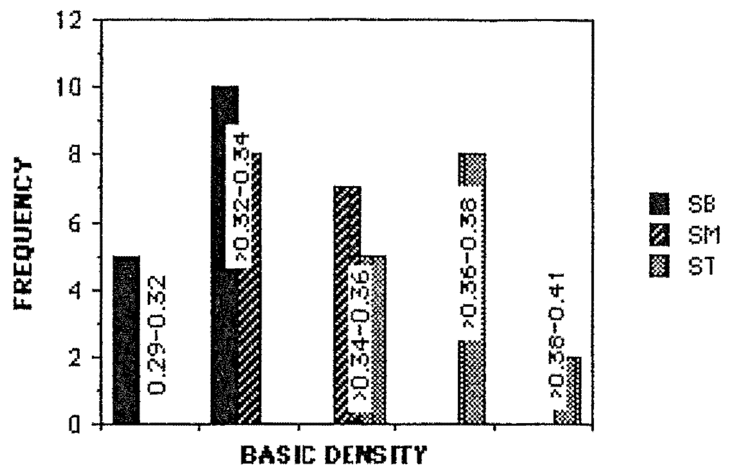


Figure 4.11 The distribution frequency of basic density at the stump height, middle and top of the straight tree.

The basic density between directions in straight trees showed a narrower variation compared to that in leaning trees. The basic density of "mark" direction varied from 0.31 to 0.39 gr/cm^3, "opposite" direction varied from 0.33 to 0.37 gr/cm^3 , and "side" direction varied from 0.33 to 0.36 gr/cm^3. The distribution frequency is illustrated in Figure 4.12.

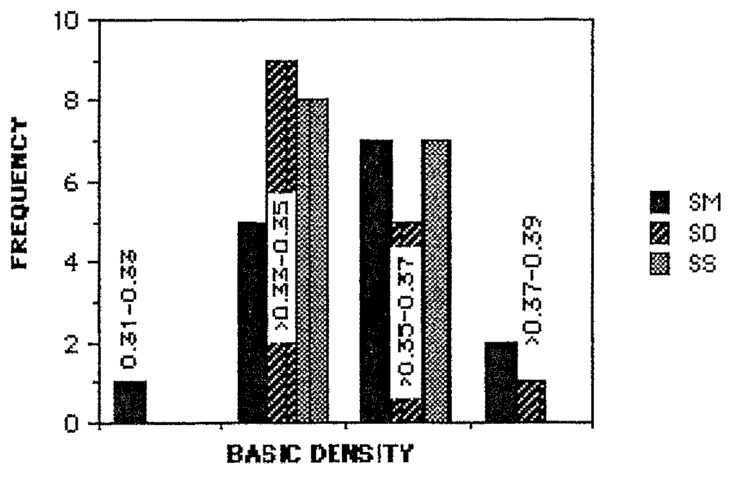


Figure 4.12 The distribution frequency of basic density in different directions in straight tree.

A similar block analysis procedure to that for basic density in leaning tree was made. The results can be seen in Table 4.18.

Table 4.18 The analysis of variance of basic density in straight trees.

Source	DF	SS	MS	F	P>T
Section	2	0.04986	0.02493	61.6	0.0001***
Direct.	2	0.00048	0.00024	0.59	0.56
Error	129	0.05217	0.00040		
Total	133	0.10251			

Note:***) significant at 0.1 % level

The differences in the sections showed a similar result to that in leaning trees, where all sections showed a very highly significant difference (0.1 % level).

Another result shows that there is no significant difference between direction in straight trees.

4.2.3.3 Comparison of basic density between straight and leaning tree

In section 4.2.3.1 and 4.2.3.2 above the basic density of leaning trees and straight trees were analyzed separately. The purpose here is to see if there are differences in the pattern of basic density between the two types of tree. However, it is possible that the effects of the type of the tree were interacting with one another. The analysis of variance was carried out for this purpose. Table 4.19 show the result of analysis of variance.

Table 4.19 Analysis of variance of basic density for type of the tree, section and direction.

Source	DF	SS	MS	F	P>T
T	1	0.0202	0.0202	42.4	0.0001***
S	2	0.0597	0.0298	62.6	0.0001***
D	2	0.0021	0.0011	2.3	0.10*
T*S	2	0.0052	0.0026	5.5	0.005**
T*D	2	0.0021	0.0010	2.15	0.11
S*D	4	0.0007	0.0002	0.41	0.80
T*S*D	4	0.0006	0.00016	0.36	0.84
Error	251	0.1196	0.00048		
Total	268	0.2104			

Note: ***) significant at level 0.1 %
**) significant at level 1 %
*) significant at level 10 %
T = tree
S = section
D = direction

The result show that there are significant differences between the type of the tree and between the sections at the 0.1 % level. Whereas the differences between direction occur at level 10 %.

The interaction between the type of the tree and the section show a significant effect to the basic density. The other interaction did not show a significant difference.

The average basic density of the type of tree at all sections and directions is illustrated in Figure 4.13.

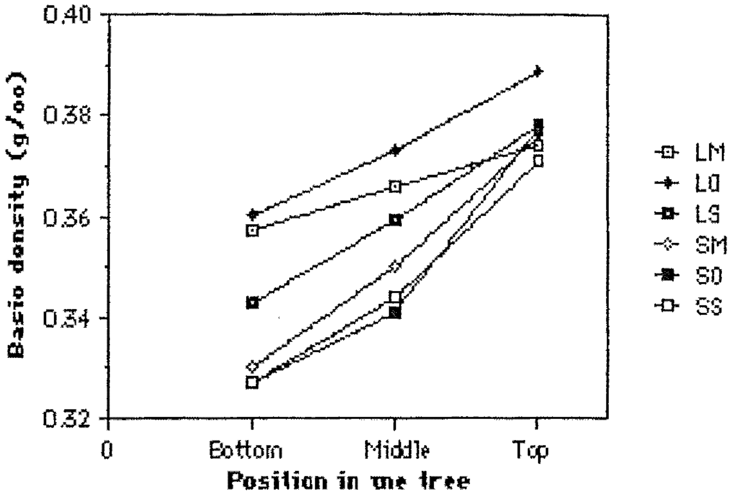


Figure 4.13 The distribution of basic density between and within the tree.

4.2.3.4 The relationship between basic density and other characteristics of wood.

It has been reported that basic density and ring width can interact with one another. For example Kennedy (1974) reported that basic density has a negative correlation with the ring width of Populus sp. The other factors that may influence the basic density are the proportion of heartwood diameter/diameter of the disk and the eccentricity.

The multiple regression analysis was carried out in order to determine this relationship. The model of multiple regression was:

$Y = a + b X_1 + c X_2 + d X_3$

Where: y = basic density (g/cc)

X_1 = The heartwood proportion

X_2= The average of ring width (cm)

X_3 = The eccentricity of the disk.

a = intercept

The parameter estimate is presented in Table 4.20.

Table 4.20 Parameter estimate of the relationship between basic density and ring width, eccentricity and heartwood proportion.

Variable	DF	Parameter estimate	Standard error	P>T
Intercept	1	0.3262	0.0322	0.0001
b	1	-0.088	0.0238	0.0004
c	1	-0.015	0.0079	0.0566
d	1	0.1161	0.0277	0.0001

Coefficient of correlation (r) = 0.54.

Table 4.20 shows that there is a negative relationship between the basic density and the ring width and the proportion of heartwood in the disk. The negative relationship of basic density and ring width is in agreement with the results found by Kennedy (1959). Whereas the negative relationship between basic density and the proportion of heartwood is related to the result of the previous analysis . The basic density increases up the tree, whereas the proportion of heartwood up the tree decreases giving a negative relationship.

Another result shows that there is a positive relationship between the eccentricity and basic density. This can be traced from the result of the analysis of variance. The basic density of leaning trees is greater than the basic density of straight trees. From another analysis of variance it was also shown that the eccentricity of leaning tree is significantly different from straight tree.

Conclusion

1. In all types of tree, bark thickness as well as diameter-over-bark decreases from the stump height to the top of the top log (about 9.6 meter above stump height). A linear relationship also exists between the bark thickness and diameter over bark. Therefore, bark thickness can be estimated from diameter over bark.

2. The mean number of rings in leaning trees differs slightly from the numbers of rings in straight trees. However, the analysis of variance showed that the ring width (growth rate) between leaning trees and straight trees was not significantly different.

3. Some of the trees produce a much higher proportion of heartwood at all levels within the tree than other trees growing under similar environmental condition. A strong correlation exists between heartwood diameter (cm) vs. diameter under bark (cm) and height of the disk within the tree. The relationship was linear without intercept.

4. The eccentricity of leaning trees shows a highly significant difference from the eccentricity of straight trees (0.1 %). The degree of eccentricity also revealed the trend of decreasing eccentricity from the butt up to the top of the tree. The analysis of variance shows significant differences

of eccentricity between the bottom and the top of the tree at level 5 %.

5. There was a great variation of green moisture content between and within the trees. Green moisture content decreases sharply from the bottom to the top of the tree, and the differences were significant at level 5 %.

6. The green moisture content within an individual tree stem is not affected by the direction within the tree ("mark" direction does not significant different from "opposite" direction and from "side" direction).

7. Green moisture content values are significantly different between the types of the tree. Normally, straight trees with high average moisture content display higher green moisture content at all positions within the stem than leaning trees with low green moisture content.

8. A correlation exists between the green moisture content and heartwood proportion. The higher the heartwood proportion, the higher the green moisture content of the wood.

9. The green density of the tree followed the trend of the distribution of green moisture content. The green density decreases from the bottom to the top of the tree, and the difference of green density at bottom of the tree compared with the top of the tree was significant at level 5 %.

10. The green density was not affected by the type of the tree nor by the direction within individual tree stems.

11. Basic density distribution within the trees showed the reverse pattern from the distribution of green moisture content and green density. The basic density sharply increases from the butt to the top of the tree.

12. Basic density values are significantly different between trees and between height within trees. Normally, leaning trees with high average basic density show higher basic density at all positions within stems compared with straight trees with low basic density.

13. Different patterns in the distribution of basic density within stems are found between straight trees and leaning trees. The basic density in leaning trees shows significant differences between the "side" direction and the "opposite" direction, whereas straight trees showed no significant differences between all directions of the disks.

14. The correlation exists between basic density vs. the ring width, heartwood proportion and the eccentricity of the disks. Basic density was positively related to the eccentricity and negatively related to ring width and heartwood proportion.

V RESULTS OF DRYING EXPERIMENT

5.1 Results

5.1.1 Air Drying

From a total of 82 sample boards in air drying, 19 boards were cut at both ends to determine moisture content. The sample size in each treatment and subsamples for moisture content determination are presented in Table 5.1.

Table 5.1 The sample size of each treatment and subsamples for moisture identification.

Boards	Samples	Subsamples
Leaning butt	23	5
Leaning top	19	5
Straight butt	21	5
Straight top	19	4
Total	82	19

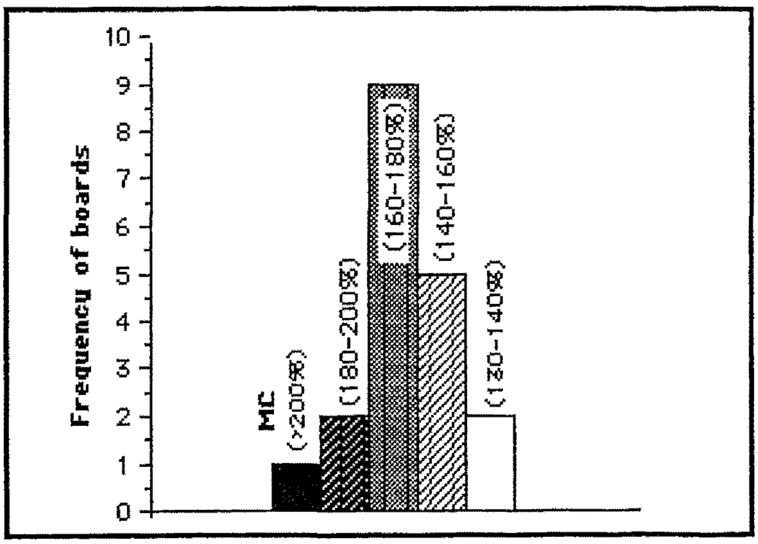
The average green moisture content and the final moisture content after 11 months of air drying are presented in Table 5.2.

Table 5.2 The average moisture content before and after 11 months air drying.

Boards	Initial MC (%)	Final MC (%)
Leaning Butt	179.0	19.2
Leaning Top	162.1	22.1
Straight Butt	175.0	20.7
Straight Top	162.3	21.9

The average green MC for all boards was 166.6 % with the moisture content ranging from 134 % to 214 %. This initial moisture content was higher than that reported earlier on disk analysis. The reason may be that the lumber was sprayed with water prior to air drying. A frequency distribution chart showing the variability of green moisture content from the 19 sample boards is given in Figure 5.1 A.

A



B

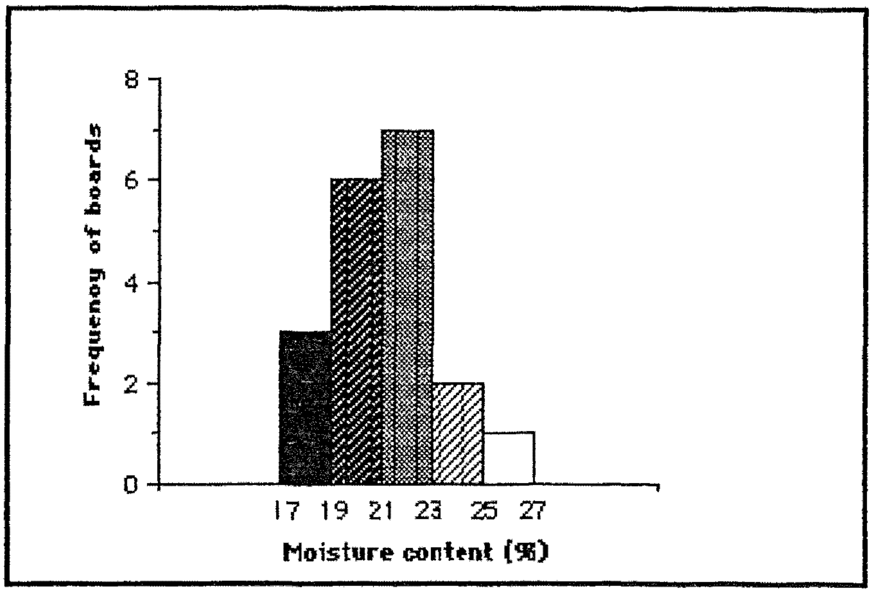


Figure 5.1 The distribution frequency of moisture content before drying and after 11 months of drying period.

The moisture loss per day from the boards of leaning butt, leaning top, straight butt and straight top was 0.49 %, 0.42 %, 0.47 % and 0.41 %, respectively. The frequency distribution for the moisture content of sample boards is presented in Figure 5.1 B. The average water loss for all timber was 0.44 % MC per-day.

The weekly minimum relative humidity and minimum and maximum temperatures of the ambient air during the first six months of the period of drying experiment is illustrated in Figure 5.2 The average temperature during the first three months of the drying period (air drying experiment began in the end of April) was below 10 ^{o}C with minimum RH about 60%. The temperature increased at the beginning of September to an average of 15 ^{o}C.

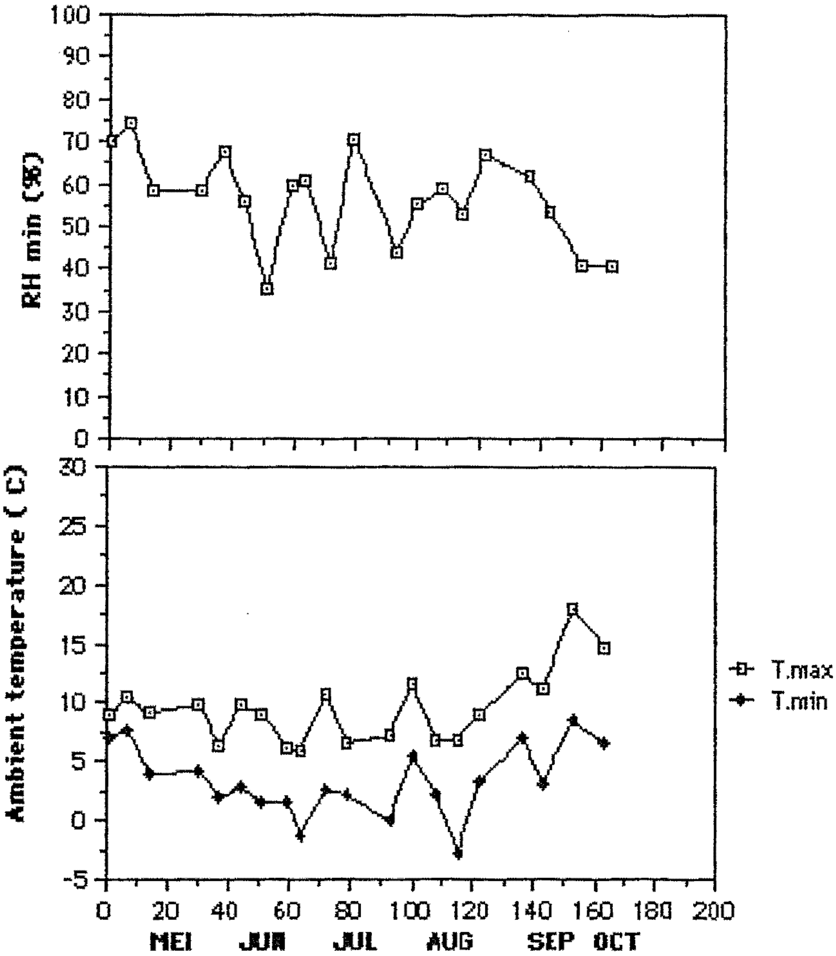


Figure 5.2 Weekly minimum relative humidity and minimum and maximum temperature of the ambient air during the first six months of the period of drying.

The rate of drying from green condition after 11 months of drying can be seen in Figure 5.3.

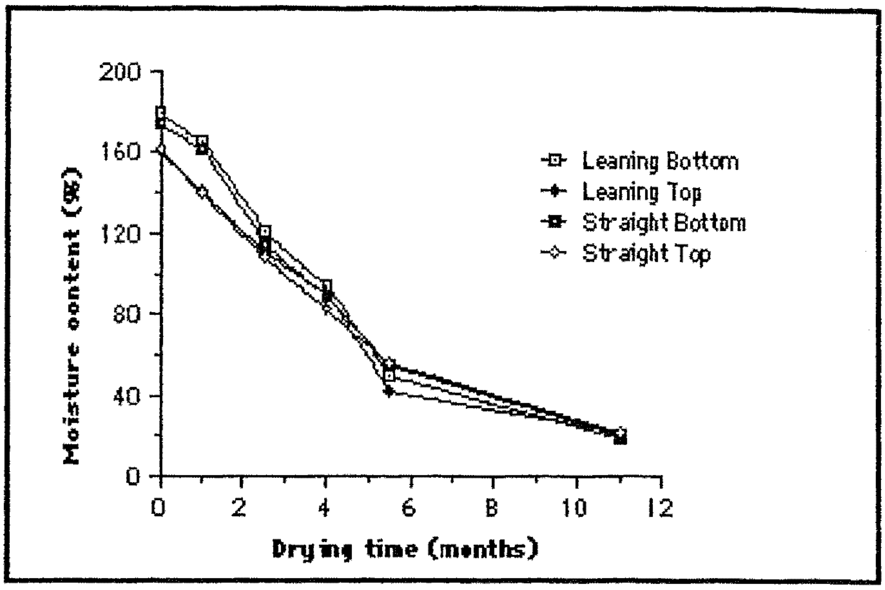


Figure 5.3 The relationship of moisture content and drying time of boards in air drying.

From 21 sample boards of the leaning bottom, 7 boards (30 %) had end checks ranging from 20 to 80 cm. Two from 19 boards (10 %) of leaning top had end checks from 10 to 15 cm. Whereas the boards of the straight bottom and straight top were 15 % and 10 % end checks (ranging from 10 to 45 cm), respectively.

5.1.2 Kiln Drying

5.1.2.1 Low Temperature Drying

The average initial moisture content was estimated from the green weight, the final moisture content and the final weight. All values of green moisture content and final moisture content of the boards in LTD experiment are presented in Appendix 3. A summary of the average and standard deviation of green moisture content and final moisture content are presented in Table 5.3.

Table 5.3 The average of green and final moisture content of the boards in low temperature drying experiment.

Boards	Initial MC (%)	Final MC (%)
Leaning Butt	163.1 (16.6)	9.1 (3.8)
Leaning Top	156.4 (9.2)	7.8 (1.4)
Straight Butt	187.6 (17.6)	9.3 (3.6)
Straight Top	164.0 (14.9)	8.3 (2.5)

Note: The values in the brackets are standard deviations.

The drying time in LTD experiment was 15.25 days, this gave 10.1 % MC loss/day for the boards from LB, while the drying rate of the boards from LT, SB and ST were 9.7 %/day, 11.7 %/day and 10.2 %/day, respectively.

The average of final moisture content of all the boards was 8.7 % with standard error 3.5 %. The lowest moisture content was 6 % and the highest was 17 %. The distribution frequency of the final moisture contents of all the boards is presented in Figure 5.4.

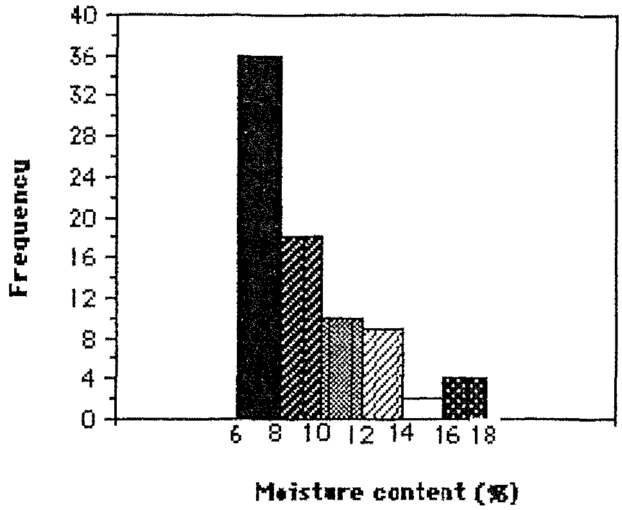


Figure 5.4 The distribution frequency of moisture content after low temperature drying.

Figure 5.4 clearly indicates that the variation in final moisture content between the boards was still very high. However, most of the boards were at a low moisture content, thus extending the drying period was not advocated, to avoid over drying. Prolonged equalizing time could be used, the drier boards would pick up moisture and at the same time the wetter boards would continue drying so that all pieces converge towards the EMC of equalizing conditions. Furthermore, because too many boards were too dry the equalizing could have begun a little earlier in the kiln schedule.

Since the sample sizes of the treatments are not equal (For example the number of boards from the leaning butt was 23, whereas the sample boards of leaning top, straight butt and straight top were 17, 20 and 19, respectively), the percentage of crook, bow and twist in each treatments was calculated separately by the formula:

$$X = (n / N) * 100 \%$$

, where x = the percentage of bow, crook or twist

n = the number of boards warps (crook, bow or twist)

N = total number of sample boards in each treatment (e.g for leaning butt = 23).

The percentage of crook, bow and twist deflection of each treatment in low temperature drying is shown in Table 5.4.

Table 5.4. Crook, bow and twist deflection percent frequency by the treatment (source of board in trees) in low temperature drying.

	Leaning		Straight		
Warp type	Butt	Top	Butt	Top	Average
Crook (mm)	(%)	(%)	(%)	(%)	(%)
0	74	88	80	100	85.5
(0-3)	9	0	5	0	3.5
(3-5)	0	6	0	0	1.5
(5-10)	9	6	15	0	7.5
(>10)	8	0	0	0	2.0
	100	100	100	100	100
Bow					
0	70	76	80	79	76.2
(0-3)	9	0	10	11	7.5
(3-5)	17	18	5	5	11.3
(5-10)	0	6	5	5	4.0
(>10)	4	0	0	0	1.0
	100	100	100	100	100
Twist					
0	48	35	50	63	49.0
(0-3)	0	0	0	0	0.0
(3-5)	26	35	15	21	24.3
(5-10)	17	18	25	11	17.7
(>10)	9	12	10	5	9.0
	100	100	100	100	100

Because the timber used in this experiment was in random widths, it was easier to sort the boards into reject and accept classification to comply with the grading rules (New Zealand Timber grading rules 1988 (NZS 3631)), in this case for framing rather than classifying by the magnitude of cup/cm width. The rejected boards in LTD based on cup limitation is presented in Table 5.5

Table 5.5 The rejection rate of the boards based on cup limitation.

	Leaning		Straight	
	Butt	Top	Butt	Top
Rejected	10.5	23.5	5.0	5.5
Accepted	89.5	76.5	95.0	94.5

The percentage of boards with check was calculated separately based on the sample size of each treatment (for example the sample size of leaning bottom in LTD was 23).

12.8 % of all sample boards showed end checking which extended from the end-surface for 6 to 30 cm. The most severe was recorded in boards of LB (30%), followed by ST boards (12.3%) LT boards and SB boards which had 11.7 % and 10 %. Two boards had initial checking, one from LT had an initial check of 12 cm which extended to 16 cm after drying. The other board from ST had an initial check of 6 cm which extended to 23 cm after drying.

5.1.2.2 Conventional Drying I (CD 1)

All values of green moisture content and final moisture content are presented in Appendix 3. A summary of the average and standard deviation of initial and final moisture content in CD I can be seen in Table 5.6.

Table 5.6 The average and standard deviation of initial and final moisture content of boards in CD I.

Boards	Initial MC (%)	Final MC (%)
Leaning butt	183.4	13.0
	(12.1)	(3.4)
Leaning top	168.1	13.3
	(13.5)	(3.4)
Straight butt	198.7	13.3
	(15.6)	(3.7)
Straight top	181.8	12.8
	(10.7)	(3.9)

The drying rate was 15.3 % MC/day for LB boards, 14.1 % MC/day for LT boards, 16.8 % MC/day for SB boards and 15.4 %MC/day for ST boards. The average of final moisture content of all the boards was 13.1 % with a standard deviation of 3.5 %. The lowest moisture content was 9 % and the highest was 20 %. The distribution frequency of the final moisture content values of all the boards is presented in Figure 5.5.

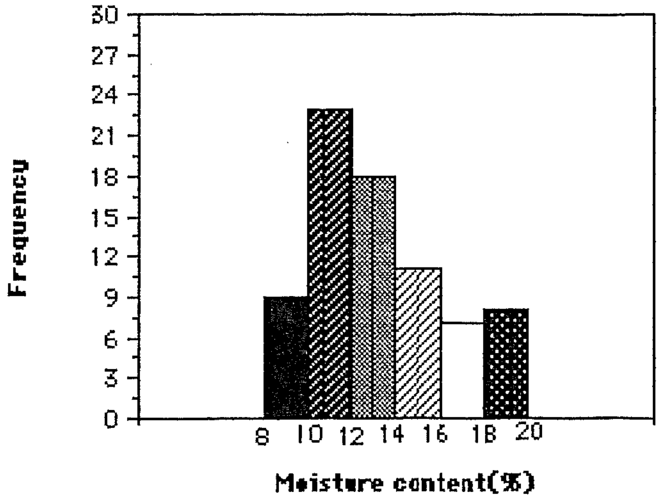


Figure 5.5 The distribution frequency of moisture content after conventional drying I.

The distribution of final moisture content in CD I was more variable than the distribution of final moisture content in LTD. This suggested that a longer equalizing time is needed at the end of drying period.

The percentage of crook, bow and twist in CD I is tabulated below (Table 5.7).

Table 5.7 Crook, bow and twist deflection percent frequency by the treatment (source of board in trees) in conventional drying I.

Warp type	Leaning Butt	Leaning Top	Straight Butt	Straight Top	Average
Crook (mm)	(%)	(%)	(%)	(%)	(%)
0	52	58	67	75	63.0
(0-3)	24	21	14	19	19.5
(3-5)	10	5	5	6	6.5
(5-10)	9	16	14	0	9.7
(>10)	5	0	0	0	1.3
	100	100	100	100	100
Bow					
0	71	63	67	75	69.0
(0-3)	0	11	9	7	6.7
(3-5)	14	16	19	6	13.7
(5-10)	10	0	5	6	5.3
(>10)	5	10	0	6	5.3
	100	100	100	100	100
Twist					
0	24	21	19	19	20.7
(0-3)	0	0	0	0	0.0
(3-5)	9	16	9	6	10.0
(5-10)	38	31	48	56	43.3
(>10)	29	32	24	19	26.0
	100	100	100	100	100

The percentage of the accepted and rejected boards based on cup limitation in the CD I experiment is presented in Table 5.8.

Table 5.8 The rejection rate of the boards based on cup limitation in CD I.

	Leaning		Straight	
	Butt	Top	Butt	Top
Rejected	19.0	36.8	9.5	31.3
Accepted	81.0	63.2	80.5	68.7

From 77 sample boards in CD I, 3 were recorded as having an initial check which opened further during drying, 18 boards checked during drying and the other 56 boards were free of checks. Of the 21 boards of LB 2 had initial checks 15 and 37 cm long which extended to 35 and 57 cm after drying. One board from LT had an initial check of 15 cm and after drying the check extended to 25 cm. Of the 18 boards (23.7%) which checked during drying check length ranged from 4.5 to 16 cm. The boards from LT were the most severely checked (31.6 %), followed by the boards from SB, LB and LT with the percentage of checked boards being: 19%, 14.3 % and 6,3 %, respectively.

5.1.2.3 Conventional Drying II (CD 11)

The summary of the average and standard deviation of initial and final moisture content of the sample boards in each treatment are presented in Table 5.9.

Table 5.9 The average and standard deviation of initial and final moisture contents of the boards in CD II.

Boards	Initial MC (%)	Final MC (%)
Leaning butt	164.1 (16.1)	11.3 (3.9)
Leaning top	154.3 (18.1)	10.3 (3.8)
Straight butt	191.1 (24.0)	11.5 (3.4)
Straight top	170.8 (12.4)	12.3 (3.1)

The drying time in CDII was 8 days, giving a drying rate of 22.4 % MC/day for boards from SB, 20%/day boards from ST, 19.1 % MC/day for the LB boards and 17.8% MC loss per day for the ST boards.

The average final moisture content of all the boards was 11.3 % with a standard deviation of 3.6 %. The lowest moisture content was 6 % and the highest was 18 %. The distribution frequency of final moisture reading from all the boards is presented in Figure 5.6.

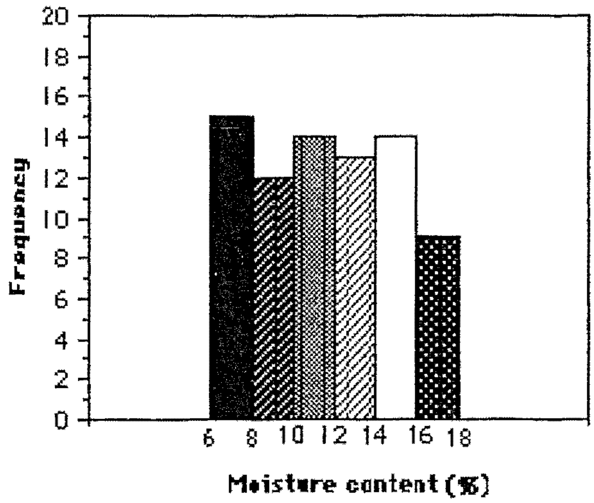


Figure 5.6 The distribution frequency of moisture content after conventional drying II.

The distribution of final moisture content was similar to that of in CDI, accordingly a longer equalizing time needed. The equalizing time in this schedule was 6 hours, and this could be prolonged to at least 10 hours (Maeglin, 1985).

Table 5.10 Crook, bow and twist deflection percent frequency by the treatment (source of board in trees) in conventional drying II.

	Leaning		Straight		
Warp type	Butt	Top	Butt	Top	Average
Crook (mm)	(%)	(%)	(%)	(%)	(%)
0	65	75	74	93	76.7
(0-3)	9	5	11	0	6.3
(3-5)	4	0	10	0	3.5
(5-10)	18	10	5	0	8.2
(>10)	4	10	0	7	5.3
	100	100	100	100	100
Bow					
0	52	40	79	60	57.7
(0-3)	4	0	11	20	8.8
(3-5)	9	25	0	13	11.8
(5-10)	22	25	5	7	14.7
(>10)	13	10	5	0	7.0
	100	100	100	100	100
Twist					
0	39	30	58	40	41.7
(0-3)	0	0	0	0	0.0
(3-5)	5	0	0	7	3.0
(5-10)	26	35	21	26	27.0
(>10)	30	35	21	27	28.3
	100	100	100	100	100

Table 5.11 summarizes the rejection rate of boards based on cup limitation in CD II.

Table 5.11 The rejection rate of boards based on cup limitation in CD II.

	Leaning		Straight	
	Butt	Top	Butt	Top
Rejected	8.7	20.0	10.5	0.0
Accepted	91.3	80.0	89.5	100

Of all sample boards 10.4 % were checked in the range of 5 to 20 cm. Also 2 boards from 23 LB boards had an initial check of 23 and 30 cm which extended to 25 and 46 cm after drying. The most severe checking was in the ST sub-sample boards (26.7 %), the second was LT boards (20 %), whereas only 10.5 % and 8.7 % were recorded to have a checking from the LB and SB board, respectively.

5.1.2.4 High Temperature Drying (HTD)

The average initial moisture content and final moisture content of each treatment is shown in Table 5.12 The drying time used in this study was 49 hours, giving a drying rate of 3.5% MC/hr, 2.8% MC/hr, 3.1 % MC/hr and 2.8 % MC/hr for boards from LB, LT, SB, and ST stems respectively.

Table 5.12 The average of initial MC and final MC of the board in high temperature drying.

Boards	Initial MC (%)	Final MC (%)
Leaning butt	157.8 (17.7)	12.0 (2.0)
Leaning top	147.6 (10.9)	11.7 (2.1)
Straight butt	159.4 (18.3)	12.7 (1.9)
Straight top	149.3 (20.1)	12.1 (1.8)

The average final moisture content of the boards was 12.0 % with standard deviation of 3.7 %. The lowest moisture content was 6 % and the highest was 20 %. The distribution frequency of final moisture reading from all the boards is presented in Figure 5.7.

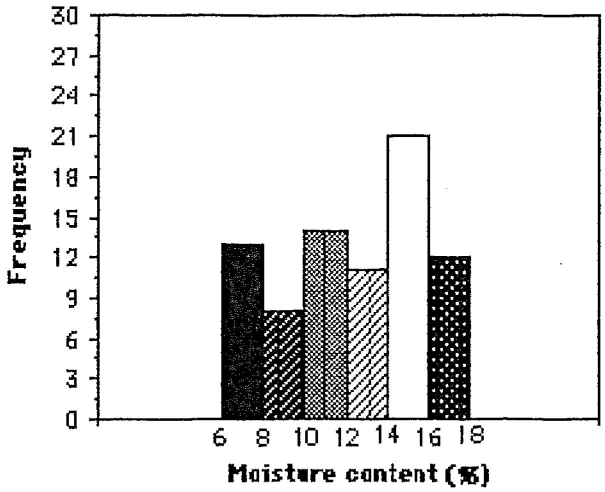


Figure 5.7 The distribution frequency of moisture content after high temperature drying.

The distribution of final moisture content in HTD also indicates a similar distribution to that of final moisture content of CD I and CD II, thus a more prolonged equalizing time is needed.

The percentage of crook, bow and twist deflection in each treatment under high temperature drying can be found in Table 5.13.

Table 5.13 Crook, bow and twist deflection percent frequency by the treatment (source of board in trees) in high temperature drying.

	Leaning		Straight		
Warp type	Butt	Top	Butt	Top	Average
Crook (mm)	(%)	(%)	(%)	(%)	(%)
0	70	63	68	69	67.5
(0-3)	17	16	27	25	21.2
(3-5)	4	10	0	6	5.0
(5-10)	9	11	5	0	6.3
(>10)	0	0	0	0	0.0
	100	100	100	100	100
Bow					
0	70	74	95	75	78.5
(0-3)	13	10	0	25	12.0
(3-5)	4	5	5	0	3.5
(5-10)	9	6	0	0	3.7
(>10)	4	5	0	0	2.3
	100	100	100	100	100
Twist					
0	65	79	73	69	71.5
(0-3)	0	0	0	0	0.0
(3-5)	13	0	9	12	8.5
(5-10)	13	16	9	13	12.7
(>10)	9	5	9	6	7.3
	100	100	100	100	100

6.3 % of all samples in high temperature treatment were rejected because of cup deformation. There were no significant differences in the severity of cupping between the treatments in the trees (LB, LT, SB and ST).

Checking in high temperature drying was a more severe defect compared to checking present in CI, CII and LTD treatments. At least 58 % of all boards were recorded to have checking in the range of 6 to 30 cm. The boards from ST were the most severe followed by SB boards, LT and LB boards. Only one of the LT boards had an initial checking (24 cm) and this extended to 31 cm after drying.

5.2 ANALYSIS

Acceptance of boards was determined using New Zealand grading rules for framing (NZSS 3631, 1988).

In this section, the analysis of variance was first carried out separately (crook, bow and twist) and then with the combination of each type of warp to determine the rejection rate.

5.2.1 Crook

Table 5.14 summarizes the percentage of rejected boards from all treatments based on the crook limitation. There was an improvement in quality of the boards in HTD and LTD methods compared to CD I and CD II. The rejection rate in CD I and CD II was reduced in HTD and LTD by 6 %. The magnitude of the improvement was derived by subtraction of the average value between drying methods being compared (for example the value of the improvement above obtained from the subtraction 17 % (CDI or CDII) by 11 % (LTD or HTD).

The effect of treatment to the rejection rate in crook limitation is presented in Figure 5.8.

Table 5.14 The percentage of rejected boards based on crook limitation, under various drying programmes.

Tree Methods	Section	LTD	CDI	CDII	HTD
L	B	17	24	26	13
L	T	12	21	20	21
S	B	15	19	15	5
S	T	0	6	7	6
	Average	11	17	17	11

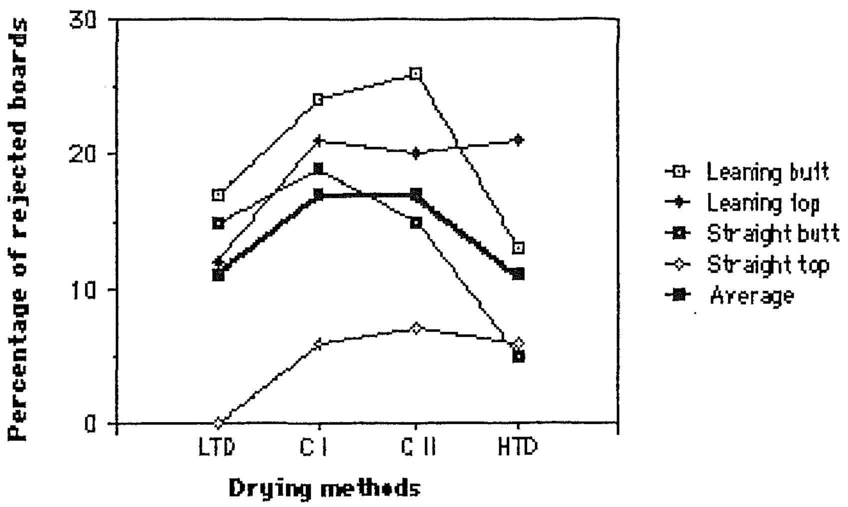


Figure 5.8 The effect of treatment on rejected boards in crook limitations.

However, this difference was not statistically highly significant (at the 0.1 level). Significant differences were shown by the type of the tree (straight vs. leaning) at level 0.01, whereas the different between the section of the tree (bottom and top) was significant at level 0.05. The percentage of rejected boards in straight trees was 10 % less than for leaning trees, and the boards from the top of the trees were 5 % less than the rejected boards from the bottom. The analysis of variance of the crook rejection rate is shown in Table 5.15.

Table 5.15 Analysis of variance of boards rejection rate based on crooked limitation.

Source	DF	F value	Pr>F
Tree	1	32.49	0.01 ***
Section	1	10.46	0.05 **
Methods	3	4.43	0.1
Tree * Section		1	6.99
	0.1		
Tree * Methods	3	0.12	0.9
Section * Methods	3	4.17	0.15

5.2.2 Bow

Bowing rejection rates are given in Table 5.16, and illustrated in Figure 5.9 The amount of rejected boards produced by CD II was reduced in high temperature drying, low temperature drying and conventional drying I by 6 %, 5 % and 2 %, respectively. This difference was not statistically significant as can be seen in Table 5.17.

Table 5.16 The percentage of rejected boards based on bow limitation, under various drying programmes.

Tree	Section	Methods			
		LTD	CDI	CDII	HTD
L	B	4	5	13	4
L	T	0	10	10	5
S	B	0	0	5	0
S	T	0	6	0	0
	average	1	5	7	2

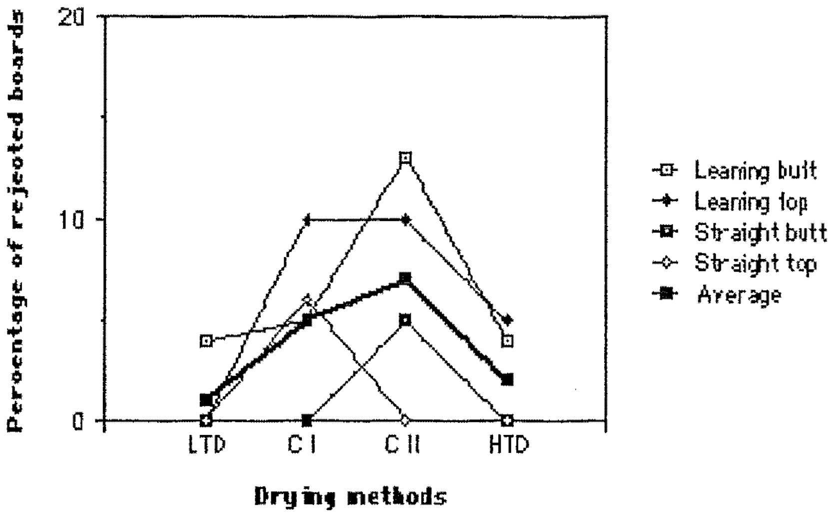


Figure 5.9 The effect of treatment on rejected boards in bow limitations.

There is a significant difference in the proportion of rejected boards between the leaning trees and straight tree (P = 0.05). The rejected boards in straight trees based on bow limitation was 10 % less then the rejected boards in leaning trees.

Table 5.17 Analysis of variance of boards rejection rate based on bowed limitation.

Source	DF	F	Pr>F
Tree	1	16.13	0.05 **
Section	1	0.09	0.8
Methods	3	3.61	0.15
Tree * Section	1	0.19	0.7
Tree * Methods	3	0.48	0.7
Section * Methods	3	2.56	0.2

The boards from the bottom logs and the top logs in this study did not show a significant difference. The rejected boards from the top of the trees were only 1 % less from the rejected boards from the butt logs.

5.2.3 Twist

The effect of subsequent treatments on twist rejection rate is presented in Table 5.19, and illustrated in Figure 5.10. It can be seen the method of drying highly influences the proportion of rejected boards because of twist. Low and high temperature drying were superior in recovery of dried boards compared to conventional drying I and conventional drying II. Figure 5.10 shows that the rejected boards in low and high temperature drying were 19 % and 21 % less than the rejected boards of conventional drying II, respectively.

Table 5.19 The percentage of rejected boards based on twist limitation, under various drying programmes.

Tree	Section				
Methods		LTD	CDI	CDII	HTD
L	B	9	29	30	9
L	T	12	32	35	5
S	B	10	24	21	9
S	T	5	19	27	6
	Average	9	26	28	7

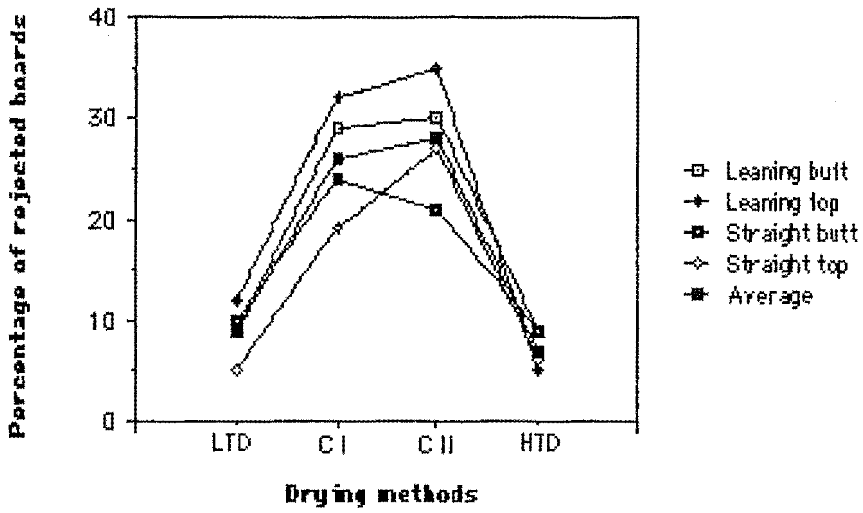


Figure 5.10 The effect of treatment on rejected boards in twist limitations.

The difference was very significant (P = 0.01). The type of tree also showed a significant difference at level P = 0.1. Whereas there were no significant differences between the sections of the tree. The result in analysis of variance is presented in Table 5.20.

Table 5.20 Analysis of variance of boards rejection rate based on twist limitation.

Source	DF	F value	Pr>F
Tree	1	5.82	0.1
Section	1	0.08	0.8
Methods	3	43.25	0.01
Tree * Section	1	0.78	0.5
Tree * Methods	3	1.10	0.5
Section * Methods	3	1.76	0.3

5.2.4 Effect of type of the tree to quality of dried board

The differences between straight and leaning trees were always statistically significant, the differences in crook limitation is significant at level 1 %, in bow at 10 % and in twist at 5 % level. Also the proportion of rejected boards from straight trees was always lower than the rejected boards from leaning trees. The effect of the type of the tree on the rejection rate is illustrated in Figure 5.11.

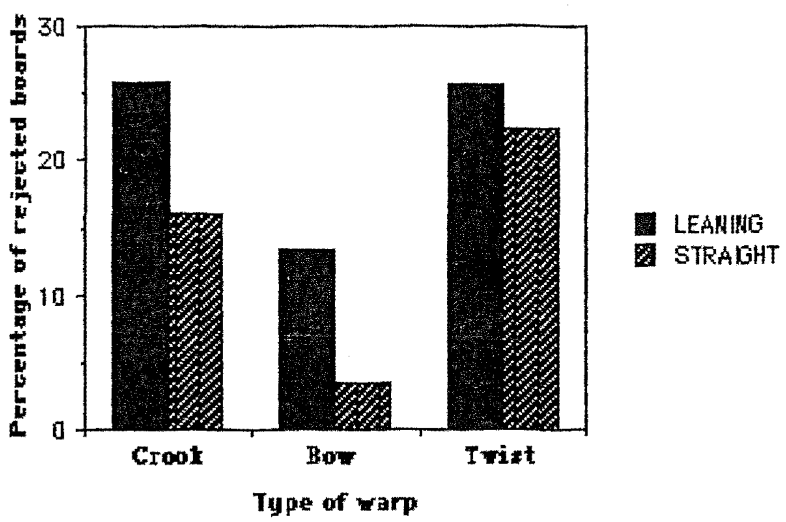


Figure 5.11 The effect of types of tree to rejection rate of dried board

5.2.5 Effect of section in the tree to quality of boards

The effect of the position of the boards in the tree was not always statistically significant. However, it should be noted that the boards from the top of the trees always indicated a lower percentage of rejected boards compared to the rejected boards from the bottom of the trees. The effect of the position of the boards to the rejection rate can be seen in Figure 5.12.

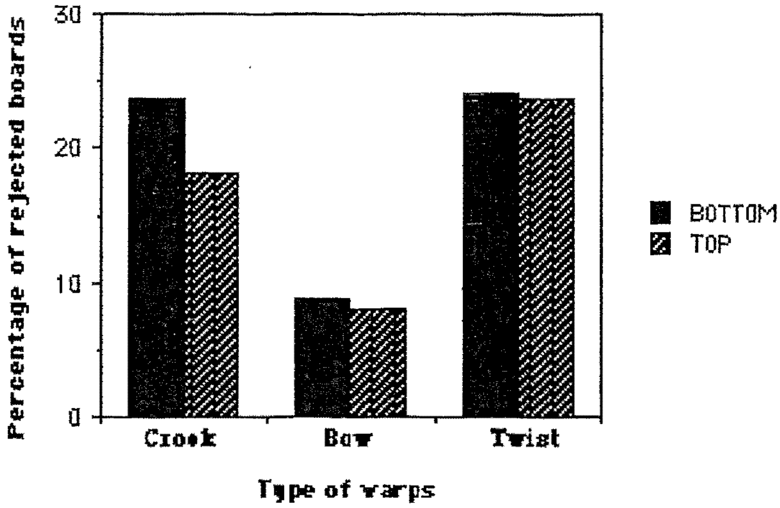


Figure 5.12 The effect of location of boards on the tree to rejection rate of dried board

5.2.6 Effect of drying methods to the quality of the boards

It can be seen that the effect of the methods of drying to the rejection rate was not always statistically significant. The only significant difference was present in twist limitation. However, generally the percentage of rejected boards of HTD were always lower than the rejected boards in both conventional drying I and II. The effect of the methods of drying to the percentage of rejected boards can be seen in Figure 5.13.

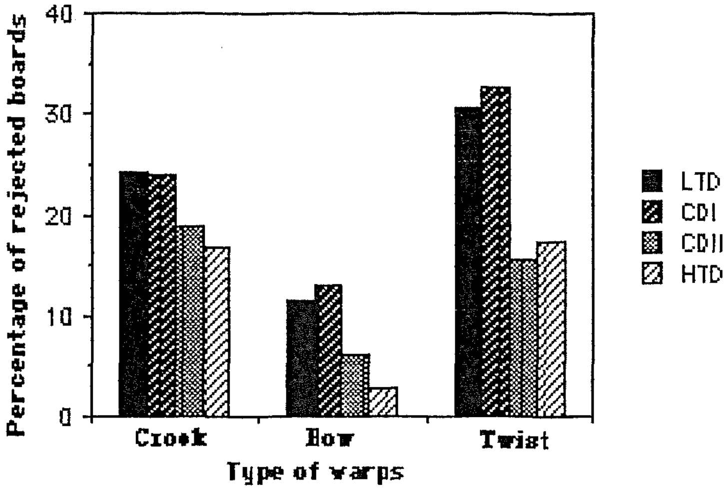


Figure 5.13 The effect of drying methods to rejection rate of dried board

5.2.7 Effect of warp (crook, bow twist and cup) on rejection rate

While the percentage of rejection rates based on the individual limitation (bow crook, twist evaluated separately) is of interest and concern, a more important question is the overall percentage rejection rate. The criteria used in this study were the New Zealand grading rules for framing timber. Rejection was based only on warp, not on knots, moisture content or spiral grain (Table 5.21).

Table 5.21 The percentage of rejected boards based on warp (bow, crook, twist and cup) limitation.

Tree	Section	LTD	CDI	CDII	HTD
		Methods			
Leaning	Butt	30.4	42.8	39.1	21.7
	Top	41.1	42	50	31.6
Straight	Butt	25	33.3	42.1	9.1
	Top	21	37.5	33.3	12.5

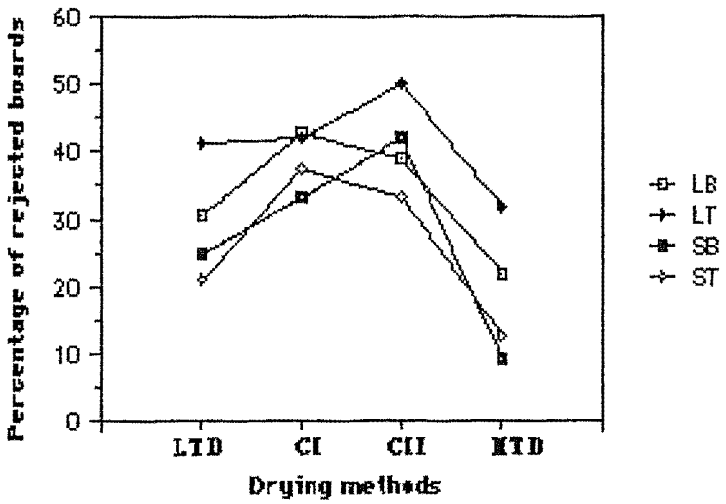


Figure 5.14 The effect of treatment on the percentage of rejected boards due to warp.

The percentage of rejected boards from straight trees was 10% less than the percentage of the rejected boards from leaning trees. These differences are statistically significant at level P = 0.05. The analysis of variance can be seen in Table 5.22.

Table 5.22 The analysis of variance of rejected boards based on warping limitation.

Source	DF	F value	Pr>F
Tree	1	18.77	0.05 **
Section	1	1.62	0.3
Methods	3	17.39	0.05 **
Tree * Section	1	2.64	0.2
Tree * Methods	3	1.34	0.4
Section * Methods	3	0.35	0.8

There were also significant differences present between the methods of drying (P = 0.05). Major differences in the rejection rate were primarily between CD II and the other methods. The percentage of rejected boards of conventional drying II were reduced by 5 %, 7 % and 14 % by CD I, LTD and HTD, respectively.

5.2.8 Shrinkage

The actual width and thickness shrinkage and the moisture content of the boards from each treatment is presented in Table 5.23.

Table 5.23 The average shrinkage in width and thickness, and the moisture content of the boards.

Tree		Methods							
		L		CI		CII		HTD	
	Sec	Sr.	MC	Sr.	MC	Sr	MC	Sr	MC
Lean	Butt	5.4*	9	3.6	12.3	3.5	8.7	3.1	11.7
		5.8**		5.9		7.3		4.7	
L	Top	4.2	7.7	2.9	17.7	4.3	5.5	3.1	13.7
		6.9		4.4		5.5		6	
S	Butt	3.9	8.7	3.9	12.2	3.9	8.3	3.4	13.3
		7.6		5.6		6.8		4.2	
S	Top	3.1	10	4.1	12.0	3.5	12.0	3.5	10.3
		6.2		4.6		6.6		5.2	

Note:*) denoted width shrinkage
**) denoted thickness shrinkage

It can be seen that the moisture content of the boards varied; thus an adjustment for shrinkage is needed to make a comparison between treatments.

The adjustment to the observed shrinkage was estimated from the relationship of moisture content and shrinkage between fibre saturation point and the moisture content of the boards. It is noted that the shrinkage of a piece of a wood normally begins at about fibre saturation point and shrinkage is fairly linear until the wood is completely dry. In this study the fibre saturation point was assumed to be 30%.

The volumetric shrinkage was estimated by adding the width and thickness shrinkages. This was based on the assumption of negligible shrinkage in longitudinal direction and gave a close estimation of the volume shrinkage (Choong, 1969)

The result of volumetric shrinkage adjusted to 10 % MC is presented in Table 5.24.

Table 5.24. Volumetric shrinkage after adjustment to 10 % MC

Tree	Sect	Methods			
		LTD	CDI	CDII	HTD
L	B	10.5	10.9	10.3	8.5
L	T	9.8	10.3	11.3	10.9
S	B	10.8	10.4	9.6	9.1
S	T	9.4	10.5	11.1	9.9

The result of analysis of variance can be seen in Table 5.25

Table 5.25 Analysis of Variance of volumetric shrinkage between treatment.

Source	DF	MS	F	Pr>F
Tree	1	1.4352	1.13	0.30
Section	1	0.8269	0.65	0.43
Methods	3	3.6924	2.91	0.05
Tree*Section	1	0.9919	0.78	0.38
Tree*Methods	3	0.2691	0.21	0.89
Section*Methods	3	3.7296	2.94	0.05
Tree*Sect*Methods	3	1.7569	1.38	0.27
ERROR	32	1.2706		

It is evident that drying methods influence the volumetric shrinkage of the boards. The results of Tukeys studentize range indicate the differences present between Low temperature drying, High temperature drying vs. volumetric shrinkage of conventional drying(I and II). The effect of drying methods on the volumetric shrinkage is illustrated in Figure 5.15.

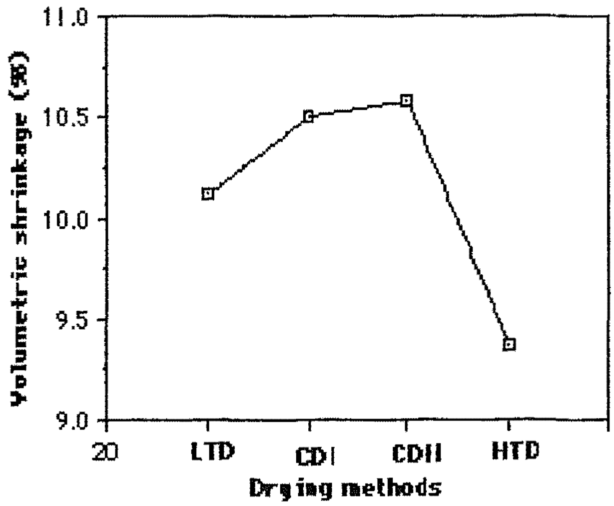


Figure 5.15 The effect of drying methods to volumetric shrinkage.

It can be concluded that in the range of 40 to 100 C (below the boiling point of water), the shrinkage was positively correlated with the temperature (drying schedule). The higher the temperature used, accordingly, the higher the volumetric shrinkage. The conclusion of this study was confirmed by the results of an investigation by Espenas (1971).

The volumetric shrinkage dropped steeply when high temperature drying was used. This result was supported by the results of investigations in high temperature drying of Yellow Poplar by Hann (1964). Hann assumed that the volumetric shrinkage was reduced in high temperature drying due to the relief of growth stresses.

The result of this study also suggested that an allowance (for shrinkage) before sawing processes should be made in accordance with the drying methods. The higher the temperature used (below 100 ^{o}C) the greater the allowance.

The average volumetric shrinkage of the leaning trees (10.3) was slightly greater than the volumetric shrinkage of straight trees (9.97 %). However, these differences were not statistically significant (Table 19).

Also there was no significant difference occurring between the bottom and the top of the trees. However, the interaction of the section and the drying methods indicate significant differences at level 5 %.

The Relationship of volumetric shrinkage and rejection rate of boards.

Shrinkage can indicate the dimension stability of a piece of board. It is assumed that the greater the shrinkage of a piece of board the more likely the boards would tend to distort in the drying process leading to their rejection. The scatter diagram of the relationship of volumetric shrinkage and the rejection rate as a result of this study is shown in Figure 5.16.

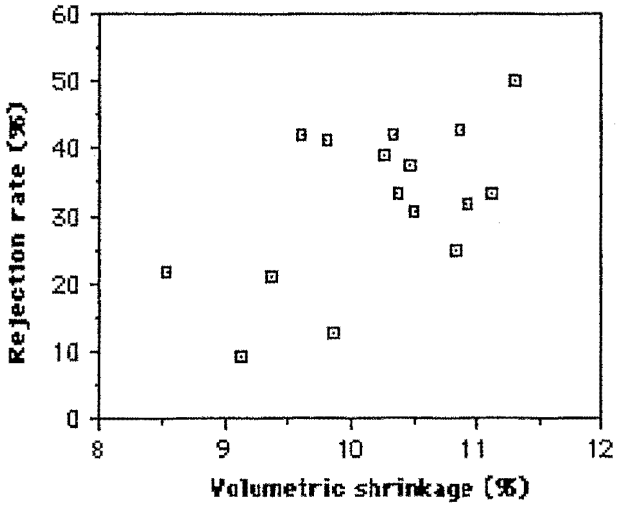


Figure 5.16 Scatter diagram of relationship of volumetric shrinkage and rejection rate of the boards.

A linear regression analysis was used to identify the correlation that occurs between the two variables. The equation fitted to the data was:

$$Y = -52.81+8.31\ X$$

Where Y = the percentage of rejection rate
X = the percentage of volumetric shrinkage.

The coefficient correlation (R) = 0.56, the regression line can be seen in Figure 5.17.

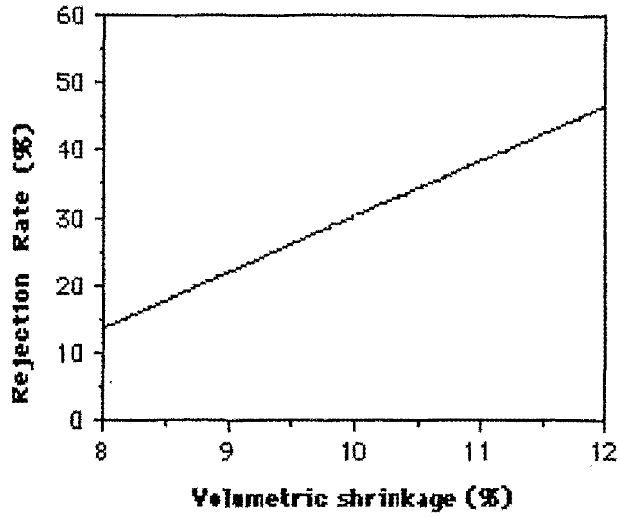


Figure 5.17 The linear regression of the relationship between volumetric shrinkage and rejection rate.

Conclusion

1. The average moisture content of boards after 11 months air drying was 21.1 % ranging from 17.2 % to 25.8 %. The boards from the leaning butt logs showed the highest drying rate (0.49 % MC/day), whereas the boards of straight top logs were the lowest (0.41 % MC/day).

2. After 15.25 days of low temperature drying, the final moisture content from green condition was 8.7 % ranging from 6 % to 17 %. The highest drying rate was recorded for the straight butt log boards (11.7 % MC/day) and the lowest was for the leaning top log boards (9.7 % MC/day). The boards from leaning butt logs show the highest percentage of crook, whereas the boards from the leaning top logs show the highest percentage of bow and twist.

3. The average final moisture content after 11 days conventional drying I was 13.1 % from the green condition. The drying rate of straight bottom

boards showed the highest drying rate (16.8 % MC/day) whereas the boards of leaning top logs showed the lowest drying rate (14.1 % MC/ day). The boards of leaning bottom logs showed the highest percentage of all types of warp and the boards of straight top logs showed the lowest.

4. The average moisture content after 8 days of conventional drying II was 11.3 % ranging from 6 to 18 %. The fastest drying rate was recorded by the boards of straight bottom logs (22.4 % MC/day and the lowest was 17.8 % MC/day of leaning top). The boards of leaning bottom logs showed the highest percentage in crook, and the boards of leaning top logs showed the highest percentage of bow and twist.

5. The final moisture content of the boards after 36 hours of high temperature drying averaged 12 %, ranging from 6 to 20 %. The highest drying rate was shown by the boards of leaning bottom logs of 3.5 % MC/hr and the slowest showed by the boards of leaning top logs and straight top logs of 2.8 % MC/hr.

6. After high temperature drying 11.25 % of the sample boards had crook more than 3 mm, 9.5 % had bow at more than 3 mm and 7.25 % had twist at more than 10 mm deflection.

7. A longer equalizing time is needed to improve uniformity (minimize variability) of final moisture content between boards

8. The rejection rate based on crook limitation for framing was not affected by the drying methods. But, it is affected by the type of the tree - straight or leaning - (statistically significance at level 0.01) and by the location of the boards

within the tree - butt or top - (significance at level 0.05).

9. The percentage of rejected boards based on bow limitation was significantly different between the leaning and the straight trees. The rejected boards of leaning trees was 10 % more than the rejected boards of straight trees. Methods and location of boards within the trees were not significantly affected the rejection rate.

10. Based on twist limitation, high temperature drying and low temperature drying were superior in recovery of dried boards compared to the conventional drying I and II methods. The types of tree and the location of boards within the tree did not indicate any statistically significance.

11. Considering all forms of distortion (bow, crook, twist and cup), the types of tree and drying methods significantly effect the rejection rate of boards for framing. Whereas the location of the boards within the tree was not significant.

12. Volumetric shrinkage values are not significantly different between trees and between location of boards within the trees. The volumetric shrinkage shows a trend of increasing shrinkage as the drying temperature increases (below the boiling point of water), and sharply decreases again when the drying temperature exceeds the boiling point of water.

13. A positive correlation exists between the percentage of volumetric shrinkage and the rejection rate of boards.

VI RESULT OF REMANUFACTURE

6.1 Crook

The results of crook and bow measurement after remanufacture are presented in Appendix 4 (5 samples per treatment). A summary of crook measurement can be seen in Table 6.1, and is illustrated in Figure 6.1.

Table 6.1. The average crook (mm) of remanufactured sample boards

		Methods			
Tree	Section	LTD	CD I	CD II	HTD
Leaning	Bottom	0.4	0.8	1.8	1.2
Leaning	Top	0.4	0.2	0.6	1.2
Straight	Bottom	0.6	0.8	1.4	0.8
Straight	Top	0.8	1.0	1.2	1.8

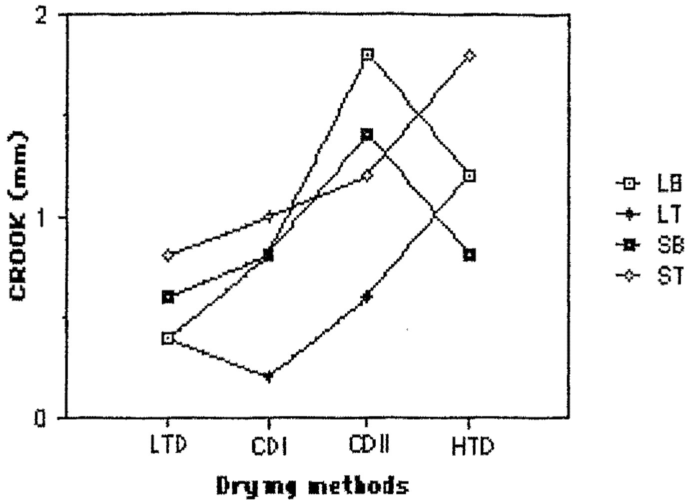


Figure 6.1 The average crook between and within the tree vs. the drying methods.

The average crook for tree types and the section of the tree showed little variation. The average crook in boards from leaning trees was 0.825 mm and in straight trees was 1.05 mm. Whereas the average of crook in the bottom and the top of the tree was 0.95 mm and 0.90 mm, respectively.

The amount of crook also showed a little variation under different drying schedules, the average crook in Low temperature drying, conventional drying I, conventional drying II and high temperature drying was 0.55 mm, 0.70 mm, 1.25 mm and 1.25 mm, respectively.

An analysis of variance was carried out to determine the differences between treatments. The result is presented in Table 6.2.

Table 6.2 Analysis of variance of crook for tree types, section and drying methods.

Source	DF	SS	MS	F	Prob>F
T	1	1.0125	1.0125	0.77	0.38
S	1	0.1125	0.1125	0.09	0.77
M	3	8.0375	2.6791	2.04	0.12
T*S	1	2.8125	2.8125	2.14	0.15
T*M	3	0.3375	0.1125	0.09	0.97
S*M	3	3.8375	1.2792	0.97	0.41
T*S*M	3	0.5375	0.1792	0.14	0.94
Error	64	84.000	1.3125		
Total	79	100.6875			

Note: T denoted tree types
S denoted section
M denoted drying methods

Table 6.2 shows that there are no significant differences between the types of tree, between the section of the tree and between the drying methods. None of the interactions showed a significant difference. It can be concluded that the deformations (in this case crook) of the boards after remanufacture was independent of kiln drying temperature.

The average of crook in each treatment after remanufacture was very small, this meant that the movement of the boards due to growth stresses after drying was very small. The reason may be that drying before ripping the boards relieved growth stress. The result of investigations by Erickson et al. (1986), Maeglin and Boone (1986) and Larsen et al.

(1986) confirmed the result of this study, which showed that saw dry rip method reduced the amount of crook in lumber.

6.2 Bow

The summary of the average bow between and within the trees and between the methods of drying can be seen in Table 6.3, and is illustrated in Figure 6.2.

Table 6.3 The average bow (mm) between, within the tree and between the methods of drying

		Methods			
Tree	Section	LTD	CD I	CD II	HTD
Leaning	Bottom	1.2	1.4	1.7	2.1
Leaning	Top	1.2	1.8	1.6	1.6
Straight	Bottom	1.0	2.2	1.2	2.0
Straight	Top	1.4	0.8	0.8	1.8

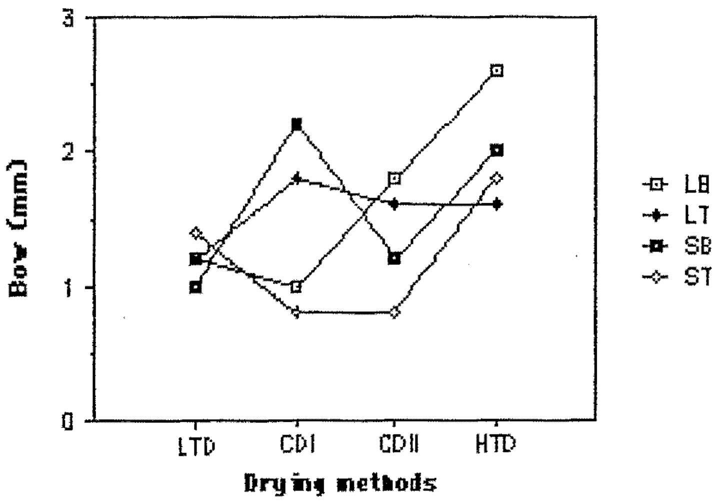


Figure 6.2 The amount of bow between and within trees vs. the drying methods.

Table 6.3 shows the average bow after remanufacture in boards from leaning trees (1.6 mm) was slightly greater than the average bow for straight trees (1.4 mm). The section of the tree also indicated a slight difference, the bottom of the tree had an average bow of 1.5 mm and the top was 1.4 mm.

The average bow varied from 1.2 mm to 1.9 mm. The lowest bow was found after low temperature drying, followed by conventional drying II and conventional drying I with the average of 1.5 and 1.3 mm, respectively. The highest bow was shown by the high temperature drying with the average of 1.9 mm.

The results show that the boards moved much more after ripping due to bowing rather than crook (section A). This suggests that some drying methods did not produce a uniform distribution of moisture throughout the boards. From the measurements it was recorded that bowing showed the maximum at the outside and decreased to the centre of the boards. This result indicated that the schedule needs prolonged equalizing treatment at the end of drying process.

Similar to the crook analysis, factorial analysis was carried out to determine the significant differences between and within trees and also between the methods of drying. The result are presented in Table 6.4.

Table 6.4 Analysis of variance of bow for tree types, section of the boards and drying methods.

Source	DF	SS	MS	F	Prob>F
T	1	0.8000	0.8000	0.60	0.44
S	1	1.2500	1.2500	0.93	0.34
M	3	7.3000	2.4333	1.81	0.15
T*S	1	0.4500	0.4500	0.33	0.56
T*M	3	1.9000	0.6333	0.47	0.70
S*M	3	1.6500	0.5500	0.41	0.75
T*S*M	3	6.6500	2.2167	1.65	0.19
Error	64	86.0000	1.3437		
Total	79	106.0000			

Table 6.4 shows that there was no significant difference between the average bow in leaning trees and straight trees. The results also indicate there is no significant differences between the section and between the interaction of the treatment.

The methods of drying which showed the most significant differences at level 15 %, from the "least significant difference" analysis suggests that significant differences occur between the average bow of high temperature drying and that of low temperature drying at level 5 %. Whereas the boards of conventional drying I and II did not show a significant difference. These results indicate that moisture content within the boards of high temperature drying treatment was not uniform compared to the boards of low temperature drying.

Uniformity of the moisture can be obtained by prolonging the equalizing treatment. In this study the equalizing time in high temperature drying was 6 hours. This step may be increased to at least 10 hours as suggested by Maeglin et al. (1985) based on the result of the investigation of the effect of high temperature drying to the characteristics of yellow poplar (Liriodendron tulipifera).

6.3 Twist

Twist after remanufacture responded differently to that observed for crook and bow. It was observed that only a small number of samples from all treatments had twist after remanufacture, and some treatments did not show any twist. The summary of the boards that showed twist after remanufacture is presented in Table 6.5.

Table 6.5 Twist of sample boards after remanufacture.

Tree	Section	Methods			
		L	CI	CII	H
L	B	0	2*	0	3*
L	T	0	0	3*	0
S	B	3**	0	0	0
S	T	0	0	0	0

Note: * twist of one board
** average twist in two boards

From the table it is clear that only a small number in all treatment showed twist after remanufacture, and no twist at all levels of drying methods for the boards from straight top.

6.4 Discoloration

Since the intended purpose of the boards from this study was for asparagus containers, the brightest, freshest, pale white colour was required. In this study the colour of boards darkened, with the loss of brightness greatest at higher drying temperatures. Boards dried at high temperatures darkened the most, taking on a light chocolate colour. Boards from low temperature drying retained a light colour. However, the discolouration of boards from conventional drying I and II was almost negligible. The result of this study suggested that high temperature drying was not suitable when the dried wood was to be used for asparagus containers. Low temperature, conventional drying I and conventional drying II would be satisfactory.

6.5 Odour

The problem encountered in drying poplar was the presence of an unpleasant odour . Zinkel et al. (1969) stated that the unpleasant odour may occur when wood containing volatile fatty acids are subjected to a hot and humid atmosphere. In addition Zinkel et al. (1969) stated that the acids are the product of anaerobic bacterial fermentation in which certain carbohydrates in the woods are broken down. Unfortunately a description of the odour as mentioned by Zinkel (1969) was not covered in this study.

The anaerobic bacterial are associated with the presence of "wet pockets" in the boards (Ward and Pong, 1980). "Wet pockets" were undoubtedly present in the boards of this study, since there is a big variation in the moisture content within the boards at the end of drying process ("wet wood" is impermeable compared to normal wood (Ward and Pong, 1980)).

The odour problem associated with the drying methods in this study had a smell like "caramel" or "burnt sugar" of the boards from high temperature drying, whereas the boards of conventional drying I, conventional drying II and low temperature drying did not indicate a strong odour. Therefore high temperature drying may be less favoured for asparagus containers.

6.6 Optimal Drying Schedule

Boards from low temperature drying, are slightly superior for asparagus containers, based on the brightness of colour, freeness from odour, uniform moisture content (indicated by freedom from casehardening), and the low levels of drying defects.

However, low temperature drying took twice as long as conventional drying II or even I (Figure 3.). The drying defects of the boards from conventional drying I and II did not significantly differ from the defects in low temperature drying. Because the odour and the loss of brightness of colour of the boards from conventional drying I and II is almost negligible, it is suggested that conventional drying I or conventional drying II be used for shorter drying time and high recovery.

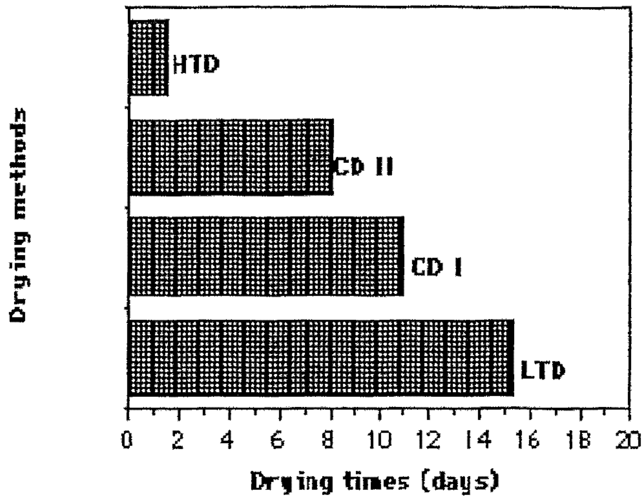


Figure 3. The comparison of drying time between the drying methods.

Boards from high temperature drying did not appear favourable for asparagus containers because of discolouration and "caramel" like odour. The boards of high temperature drying also showed a high degree of bow, indicating a large spread in moisture content within the boards due to short equalizing time, which could be taken account of quite easily.

Boards from high temperature drying, however, can be used for other purposes (for example for door parts which will be painted in utilization). A high temperature drying schedule is better for drying larger dimension boards. The loss of boards due to rejection before remanufacture of high temperature drying is better than the boards of other methods (previous section). The problem with uniformity of moisture content distribution within the boards can be countered by prolonging the equalizing time to at least 10 hours (Maeglin, 1985). Longer equalizing time will also contribute to minimizing the effects of growth stresses (Boone and Maeglin, 1980).

Conclusions.

1. The average of crook after remanufacture was very small. The effect of types of tree and location of the boards within the tree and also the drying methods on the crook did not show a significant difference. This may be due to the release of growth stresses during drying of the flitches.

2. There were no significant differences of bow between and within the trees. The significant differences appeared within the methods of drying. High temperature dried boards bowed more than those of low temperature drying.

3. Although the amount of rejects is higher in CD I and CD II, once the boards are remanufactured the amounts of rejects in remanufactured material is the virtually the same, (note: this is not general conclusion: rather the choice of asparagus container which requires only short lengths and narrow widths, is ideal when wishing to process distorted boards).

4. The boards darkened and lost brightness after higher drying temperatures. Boards dried at high temperature drying darkened the most, whereas boards of low temperature drying retained a superior colour and brightness. Boards from conventional drying I and II fell between boards of HTD and boards of LTD, but were more similar to the LTD boards.

5. The odour like "caramel" present in the boards after high temperature drying, made the boards unfavorable for asparagus containers. However, high temperature drying methods can be economic for purposes other than for asparagus containers. High temperature drying remains an attractive processing

option because of the high recovery, due to less warp.

6. The conventional drying I or II schedule can be used for drying the flitches of Populus "androscoggin" for asparagus containers. The boards dry faster and there is no significant difference in quality of boards from that which can be achieved by low temperature drying.

7. The high temperature drying schedule used in this study should be modified (especially by increasing the equalizing time) to produce better quality boards for other purposes than for asparagus containers.

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Appendix 1. The general characteristics of the trees from disks analysis.

1A1. Leaning bottom

	Dob (cm)	Dub (cm)	HW. (cm)	HW Av. (cm)	dob Av. (cm)	Dub Av. (cm)	Ratio (HW/Dub)	Ecc.
	1	2	3	4	5	6	7	8
Tr.No								
1	53.2 (47)	51.6 (45.2)	33 (29)	31	50.1	48.4	0.64 (0.64)	1.14
2	47.7 (43)	46 (41.6)	37 (37)	37	45.3	43.8	0.80 (0.89)	1.11
3	50.2 (44.1)	48.3 (42.5)	36 (30)	33	47.1	45.4	0.75 (0.71)	1.14
4	43 (39)	41.4 (37.5)	29 (21.5)	25.2	41	39.4	0.70 (0.57)	1.10
5	52.8 (45.1)	51 (43.4)	42 (36)	39	48.9	47.2	0.82 (0.83)	1.18
6	43 (40.5)	41.4 (39.2)	28 (29)	28.5	41.7	40.3	0.68 (0.74)	1.06
7	47.1 (45.6)	46 (44.4)	29 (29)	29	46.3	45.2	0.63 (0.65)	1.04
8	55 (51.6)	53 (50.2)	28 (20)	24	53.3	51.6	0.53 (0.40)	1.06
9	54.1 (43.5)	52.2 (41.8)	34 (32)	33	48.8	47	0.65 (0.77)	1.25
10	47.5 (40)	46.3 (38.4)	31 (30)	30.5	43.7	42.3	0.67 (0.78)	1.21
11	57.2 (51.2)	55 (49.2)	41 (40.5)	40.7	54.2	52.1	0.75 (0.82)	1.12
12	50.9 (40.4)	48 (38.6)	32 (25)	28.5	45.6	43.3	0.67 (0.65)	1.24
13	50.2 (46.5)	48.3 (44.9)	37 (34)	35.5	48.3	46.6	0.77 (0.76)	1.08
14	46.8 (41)	45.1 (39.4)	34 (30)	32	43.9	42.2	0.75 (0.76)	1.14
15	47.6 (44.9)	45.9 (43.6)	34 (31)	32.5	46.2	44.7	0.74 (0.71)	1.05

1A2. Leaning middle

	Dob (cm)	Dub (cm)	HW. (cm)	HW Av. (cm)	Ratio (HW/Dub)	dob Av. (cm)	Dub Av. (cm)	Ecc.
Tr.No								
1	42 (37.3)	40.2 (36.2)	24 (20)	22	0.60 (0.55)	39.65	38.2	1.11
2	35.1 (30.9)	34.1 (29.7)	26 (22)	24	0.76 (0.74)	33.00	31.9	1.15
3	38.5 (32.6)	37 (31.3)	21.5 (20)	20.7	0.58 (0.64)	35.55	34.2	1.18
4	33.8 (29.7)	32.7 (28.3)	18 (16)	17	0.55 (0.57)	31.75	30.5	1.16
5	40.6 (37.1)	39 (36.1)	27 (25)	26	0.69 (0.69)	38.85	37.6	1.08
6	31.1 (29.4)	30 (28.3)	19 (18)	18.5	0.63 (0.64)	30.25	29.2	1.06
7	33 (32.1)	31.8 (30.8)	21 (10)	15.5	0.66 (0.32)	32.55	31.3	1.03
8	40.6 (33)	39.1 (32)	37 (36)	36.5	0.95 (0.72)	36.80	35.6	1.22
9	49.5 (32.8)	48.5 (31.2)	41 (21)	31	0.85 (0.67)	41.15	39.9	1.55
10	34.2 (30.5)	32.9 (29.3)	19.5 (19)	19.2	0.59 (0.65)	32.35	31.1	1.12
11	41.8 (37)	40.3 (35.8)	30 (29)	29.5	0.74 (0.81)	39.40	38.1	1.13
12	36.2 (32.4)	35 (31.3)	18 (17.5)	17.7	0.51 (0.56)	34.30	33.2	1.12
13	35.8 (33.1)	34.6 (32)	24 (22)	23	0.69 (0.69)	34.45	33.3	1.08
14	34.3 (31)	33.2 (29.9)	21 (21)	21	0.63 (0.70)	32.65	31.6	1.11
15	39 (35)	37.6 (33.8)	26 (23)	24.5	0.69 (0.68)	37.00	35.7	1.11

1A3. Leaning top

Tr.No	Dob (cm)	Dub (cm)	HW. (cm)	HW Av. (cm)	Ratio (HW/Dub)	dob Av. (cm)	Dub Av. (cm)	Ecc.
1	34.2 (33.7)	33 (32.7)	15 (16)	15.5	0.45 (0.49)	33.95	32.8	1.01
2	28.9 (25.8)	27.6 (24.8)	18 (13)	15.5	0.65 (0.52)	27.35	26.2	1.11
3	30.7 (28.8)	29.7 (27.6)	13 (13)	13	0.44 (0.47)	29.7	28.6	1.08
4	27.2 (21.7)	26 (20.6)	11 (13)	12	0.42 (0.63)	24.45	23.3	1.26
5	28.4 (27.1)	27.4 (26.2)	14 (13)	13.5	0.51 (0.50)	27.75	26.8	1.05
6	26.5 (25.3)	25.3 (24.5)	15 (14)	14.5	0.59 (0.57)	25.90	24.9	1.03
7	30 (28.1)	29.1 (27.2)	16 (14)	15	0.55 (0.51)	29.05	28.1	1.07
8	31.2 (29.9)	30.3 (28.8)	16 (15)	15.5	0.53 (0.52)	30.55	29.5	1.05
9	25.9 (23.1)	24.5 (21.9)	12 (11)	11.5	0.49 (0.50)	24.50	23.2	1.12
10	24.2 (22.9)	23.5 (22.1)	12 (11)	11.5	0.51 (0.50)	23.55	22.8	1.06
11	31.6 (27.5)	30.4 (26.2)	19 (16)	17.5	0.63 (0.61)	29.55	28.3	1.16
12	29.1 (28)	28 (27.1)	10 (10)	10	0.36 (0.37)	28.55	27.5	1.03
13	30.1 (27.6)	28.8 (26.5)	15 (13)	14	0.52 (0.49)	28.85	27.6	1.09
14	27.5 (25.6)	26.7 (24.8)	13 (13)	13	0.49 (0.52)	26.55	25.7	1.08
15	31.8 (28.8)	30.9 (27.8)	19 (17)	18	0.61 (0.61)	30.30	29.3	1.11

Note: The value in the brackets denoted the value of minor diameter.

1B1.Straight bottom.

Tr.No	Dob (cm)	Dub (cm)	HW. (cm)	Dub Av. (cm)	Dob Av. (cm)	HW. Av. (cm)	Rat. (HW/Dub)	Ecc.
16	52.5 (49)	50.7 (47.8)	37 (34)	49.2	50.75	35.50	0.73 (0.71)	1.06
17	51.9 (49.8)	50.4 (48.2)	38 (36)	49.3	50.85	37.00	0.75 (0.75)	1.05
18	51 (46.2)	49.5 (45.1)	39 (31)	47.3	48.60	35.00	0.79 (0.69)	1.10
19	41.5 (37.7)	39.9 (36.2)	29.5 (26.5)	38.0	39.60	28.00	0.74 (0.73)	1.10
20	55.4 (47.7)	53.5 (46.2)	37 (32.5)	49.8	51.55	34.75	0.69 (0.70)	1.16
21	41 (38)	40 (36.8)	38 (24)	38.4	39.5	31	0.77 (0.65)	1.09
22	45 (39)	43.5 (38)		40.7	42			1.14
23	49 (48)	47.5 (46.6)	34 (33.5)	47.0	48.5	33.7	0.72 (0.72)	1.02
24	47.4 (44)	45.5 (42.3)	36 (34)	43.9	45.70	35.00	0.79 (0.80)	1.08
25	54.6 (52.6)	53.3 (51.2)	37 (38)	52.2	53.60	37.50	0.69 (0.74)	1.04
26	46 (44)	45.5 (42.8)	34 (34)	44.1	45.00	34.00	0.75 (0.79)	1.06
27	44.8 (42.5)	43.5 (41.2)	30 (29)	42.3	43.65	29.50	0.69 (0.70)	1.06
28	51.8 (51.8)	50.3 (50.4)	38 (37)	50.3	51.80	37.50	0.76 (0.73)	1.00
29	49 (44)	47.6 (42.5)	29 (29)	45.0	46.50	29.00	0.61 (0.68)	1.12
30	51 (46)	49.4 (44.5)	37 (31)	46.9	48.50	34.00	0.75 (0.70)	1.11

1B2. Straight middle

Tr.No	Dob (cm)	Dub (cm)	HW. (cm)	Dub Av. (cm)	Dob Av. (cm)	HW. Av. (cm)	Rat. (HW/Dub)	Ecc.
16	38.9 (35)	37.7 (34)	25 (23)	35.8	36.95	24.00	0.66 (0.68)	1.11
17	41.1 (38)	39.7 (36.8)	29 (28)	38.2	39.55	28.50	0.73 (0.76)	1.08
18	39 (36.1)	37.9 (35)	27 (25)	36.4	37.55	26.00	0.71 (0.71)	1.08
19	33.2 (32.1)	32.2 (31)	21 (21)	31.6	32.65	21.00	0.65 (0.68)	1.04
20	38.5 (37)	37.3 (35.9)	26 (24.5)	36.6	37.75	25.25	0.70 (0.68)	1.04
21	30 (30)	29 (29)	18 (18)	29	30.00	18.00	0.62 (0.62)	1.00
22	33.2 (30.1)	32.2 (29.3)	23 (17)	30.7	31.65	20.00	0.71 (0.58)	1.10
23	36.2 (35.2)	35 (33.9)	24.5 (24.5)	34.4	35.70	24.50	0.70 (0.72)	1.03
24	38.7 (34.5)	37.2 (33.3)	28.5 (23.5)	35.2	36.60	26.00	0.77 (0.71)	1.12
25	42.2 (37.9)	41 (36.6)	32 (27)	38.8	40.05	29.50	0.78 (0.74)	1.12
26	38.1 (37)	37.1 (35.9)	27 (26)	36.5	37.55	26.50	0.73 (0.72)	1.03
27	32.9 (32.4)	31.9 (31.3)	21 (21)	31.6	32.65	21.00	0.66 (0.67)	1.02
28	37.5 (35.9)	36.1 (34.8)	24.5 (22.5)	35.4	36.70	23.50	0.68 (0.65)	1.04
29	38.5 (38.5)	37.3 (37.2)	24 (23.5)	37.2	38.50	23.75	0.64 (0.63)	1.00
30	36.4 (35.1)	35.8 (33.9)	22 (21)	34.8	35.75	21.50	0.61 (0.62)	1.06

1B3. Straight top

Tr.No	Dob (cm)	Dub (cm)	HW. (cm)	Dub Av. (cm)	Dob Av. (cm)	HW. Av. (cm)	Rat. (HW/Dub)	Ecc.
16	32 (30.8)	31.1 (29.7)	18 (16)	30.4	31.40	17.00	0.58 (0.54)	1.05
17	35.2 (32)	33.7 (30.9)	23 (23)	32.3	33.60	23.00	0.68 (0.74)	1.09
18	31.2 (31)	30.4 (30.1)	18 (19)	30.2	31.10	18.50	0.59 (0.63)	1.01
19	31.6 (28.7)	30.5 (27.6)	15 (15)	29.0	30.15	15.00	0.49 (0.54)	1.11
20	31.5 (31.1)	30.5 (30)	18 (18)	30.2	31.30	18.00	0.59 (0.60)	1.02
21	25.6 (24.6)	24.5 (23.4)	13 (13)	23.9	25.10	13.00	0.53 (0.56)	1.05
22	27.5 (25.1)	26.5	14 (24.1)	25.3	26.30 (14)	14.00	0.53 (0.58)	1.10
23	30.9 (30.5)	29.9 (29.5)	18 (17.5)	29.7	30.70	17.75	0.60 (0.59)	1.01
24	36.1 (34.7)	35 (33.5)	23 (21)	34.2	35.40	22.00	0.66 (0.63)	1.04
25	34.3 (32)	33 (31.9)	22 (18)	32.4	33.15	20.00	0.67 (0.56)	1.03
26	35 (33.2)	33.4 (32)	23 (22)	32.7	34.10	22.50	0.69 (0.69)	1.04
27	29.3 (28)	28.4 (27)	16 (16)	27.7	28.65	16.00	0.56 (0.59)	1.05
28	30.9 (30.5)	29.9 (29.4)	15 (14)	29.6	30.70	14.50	0.50 (0.48)	1.02
29	33.5 (33.1)	32.2 (32)	18.5 (18)	32.1	33.30	18.25	0.57 (0.56)	1.01
30	34 (32.2)	33 (31.8)	19 (17)	32.4	33.10	18.00	0.58 (0.53)	1.04

Note: av. is the average of major diameter and minor diameter value

Appendix 2. Green moisture content, green density and basic density from disks anallysis.

Tree No.	Sect.	Dir. (%)	Green MC (%)	Green Dens. (gr/cm^3)	Basic Dens.
1	2	3	4	5	6
1	B	M	115.36	0.74	0.34
		O	98.76	0.77	0.39
		S1	112.68	0.74	0.35
		S2	107.85	0.73	0.35
1	M	M	115.87	0.75	0.35
		O	100.25	0.76	0.38
		S1	130.34	0.79	0.34
		S2	114.29	0.76	0.35
1	T	M	109.02	0.77	0.37
		O	97.08	0.72	0.37
		S1	106.47	0.77	0.37
		S2	101.37	0.75	0.37
2	B	M	151.72	0.86	0.34
		O	144.95	0.92	0.37
		S1	163.37	0.89	0.34
		S2	156.80	0.91	0.35
2	M	M	141.98	0.85	0.35
		O	126.58	0.89	0.39
		S1	144.13	0.85	0.35
		S2	147.37	0.91	0.37
2	T	M	121.88	0.85	0.38
		O	119.18	0.86	0.39
		S1	123.02	0.81	0.36
		S2	125.18	0.88	0.39
3	B	M	122.22	0.88	0.40
		O	134.54	0.82	0.35
		S1	127.45	0.79	0.35
		S2	127.27	0.80	0.35
3	M	OM1	98.23	0.84	0.42
		OM2	115.52	0.75	0.35
		S1	112.88	0.74	0.35
		S2	126.49	0.80	0.35
3	T	OM1	110.96	0.83	0.39
		OM2	107.35	0.80	0.39
		S1	101.27	0.85	0.42
		S2	119.89	0.82	0.37

1	2	3	4	5	6
4	B	M	122.04	0.84	0.38
		O	127.48	0.82	0.36
		S1	129.41	0.79	0.35
		S2	122.32	0.82	0.37
4	M	M	114.54	0.77	0.36
		O	113.24	0.82	0.38
		S1	120.00	0.80	0.36
		S2	119.14	0.79	0.36
4	T	OM1	89.41	0.82	0.43
		OM2	100.00	0.80	0.40
		S1	103.27	0.83	0.41
		S2	108.11	0.79	0.38
5	B	M	148.29	0.86	0.35
		O	136.51	0.87	0.37
		S1	153.17	0.88	0.35
		S2	150.28	0.87	0.35
5	M	M	131.38	0.82	0.35
		O	116.18	0.87	0.40
		S1	116.17	0.91	0.42
		S2	128.03	0.88	0.39
5	T	OM1	119.27	0.82	0.37
		OM2	119.56	0.80	0.36
		S1	126.67	0.81	0.36
		S2	124.01	0.82	0.37
6	B	OM1	138.04	0.82	0.34
		OM2	129.71	0.86	0.38
		S1	148.37	0.85	0.34
		S2	150.85	0.81	0.32
6	M	M	126.49	0.84	0.37
		O	120.05	0.84	0.38
		S1	132.65	0.79	0.34
		S2	141.49	0.80	0.33
6	T	OM1	123.40	0.80	0.36
		OM2	76.71	0.87	0.49
		S1	99.64	0.83	0.42
		S2	82.62	0.84	0.46
7	B	M	128.52	0.73	0.32
		O	130.50	0.74	0.32
		S1	117.74	0.71	0.32
		S2	117.74	0.69	0.31
7	M	M	112.40	0.71	0.33
		O	101.08	0.73	0.36
		S1	99.74	0.68	0.34
		S2	94.84	0.69	0.35

1	2	3	4	5	6
7	T	OM1	100.54	0.70	0.35
		OM2	107.76	0.76	0.36
		S1	105.88	0.73	0.35
		S2	107.69	0.74	0.36
8	B	M	136.55	0.83	0.35
		O	137.92	0.80	0.34
		S1	138.26	0.85	0.36
		S2	147.93	0.86	0.35
8	M	M	119.02	0.88	0.40
		O	121.66	0.84	0.38
		S1	140.64	0.83	0.34
		S2	133.82	0.85	0.36
8	T	M	110.87	0.76	0.36
		O	113.87	0.79	0.37
		S1	116.16	0.77	0.36
		S2	105.88	0.76	0.37
9	B	M	140.00	0.88	0.37
		O	138.00	0.95	0.40
		S1	155.91	0.89	0.35
		S2	131.73	0.90	0.39
9	M	M	129.90	0.98	0.43
		O	148.80	1.06	0.42
		S1	121.57	0.85	0.38
		S2	122.01	0.87	0.39
9	T	M	140.93	0.90	0.37
		O	110.18	0.90	0.43
		S1	140.63	0.88	0.36
		S2	129.73	0.86	0.37
10	B	OM1	124.82	0.81	0.36
		OM2	112.77	0.82	0.39
		S1	133.63	0.87	0.37
		S2	139.13	0.84	0.35
10	M	OM1	125.15	0.79	0.35
		OM2	114.93	0.76	0.35
		S1	140.46	0.80	0.33
		S2	103.95	0.82	0.40
10	T	M	135.71	0.88	0.37
		O	123.30	0.84	0.38
		S1	127.72	0.89	0.39
		S2	115.56	0.91	0.42

1	2	3	4	5	6
11	B	M	142.08	0.90	0.37
		O	148.10	0.86	0.35
		S1	167.61	0.96	0.36
		S2	155.35	0.87	0.34
11	M	M	129.39	0.83	0.36
		O	129.23	0.86	0.38
		S1	136.45	0.89	0.38
		S2	147.49	0.95	0.38
11	T	M	110.71	0.81	0.39
		O	116.55	0.85	0.39
		S1	123.30	0.88	0.40
		S2	123.59	0.82	0.37
12	B	M	151.79	0.88	0.35
		O	118.57	0.81	0.37
		S1	129.17	0.77	0.34
		S2	130.98	0.78	0.34
12	M	M	128.57	0.81	0.35
		O	118.98	0.77	0.35
		S1	137.29	0.81	0.34
		S2	127.05	0.82	0.36
12	T	OM1	120.31	0.81	0.37
		OM2	114.29	0.77	0.36
		S1	130.63	0.82	0.36
		S2	113.82	0.77	0.36
13	B	M	159.12	0.89	0.34
		O	137.59	0.81	0.34
		S1	160.68	0.89	0.34
		S2	142.94	0.83	0.34
13	M	M	126.87	0.80	0.35
		O	130.66	0.81	0.35
		S1	135.74	0.84	0.35
		S2	131.62	0.81	0.35
13	T	M	104.95	0.76	0.37
		O	93.04	0.80	0.41
		S1	102.70	0.78	0.38
		S2	117.82	0.78	0.36
14	B	M	127.27	0.82	0.36
		O	162.40	0.91	0.35
		S1	148.49	0.86	0.35
		S2	153.37	0.89	0.35

1	2	3	4	5	6
14	M	M	146.64	0.86	0.35
		O	143.90	0.83	0.34
		S1	145.50	0.84	0.34
		S2	150.00	0.85	0.34
14	T	M	112.26	0.76	0.36
		O	115.60	0.79	0.37
		S1	114.29	0.78	0.37
		S2	121.67	0.79	0.36
15	B	M	132.56	0.87	0.37
		O	163.78	0.88	0.33
		S1	145.03	0.86	0.35
		S2	154.24	0.84	0.33
15	M	M	145.35	0.87	0.35
		O	154.72	0.90	0.35
		S1	140.08	0.81	0.34
		S2	161.82	0.91	0.35
15	T	M	117.31	0.78	0.36
		O	113.48	0.77	0.36
		S1	118.29	0.77	0.35
		S2	114.29	0.77	0.36
16	B	OM1	153.46	0.84	0.33
		OM2	146.91	0.79	0.32
		S1	154.21	0.80	0.31
		S2	138.21	0.79	0.33
16	M	OM1	132.80	0.78	0.34
		OM2	142.07	0.79	0.33
		S1	132.78	0.78	0.33
		S2	145.69	0.80	0.33
16	T	M	105.16	0.83	0.40
		O	111.30	0.77	0.36
		S1	121.09	0.78	0.35
		S2	121.07	0.78	0.35
17	B	M	160.42	0.85	0.33
		O	141.23	0.80	0.33
		S1	158.62	0.82	0.32
		S2	154.10	0.82	0.32
17	M	OM1	130.93	0.88	0.38
		OM2	146.75	0.84	0.34
		S1	151.52	0.86	0.34
		S2	152.63	0.86	0.34
17	T	OM1	127.88	0.84	0.37
		OM2	128.37	0.94	0.41
		S1	147.83	0.90	0.37
		S2	141.31	0.91	0.38

1	2	3	4	5	6
18	B	OM1	140.48	0.87	0.36
		OM2	168.49	0.87	0.32
		S1	134.33	0.78	0.33
		S2	160.48	0.86	0.33
18	M	OM1	148.37	0.87	0.35
		OM2	145.06	0.84	0.34
		S1	153.78	0.88	0.35
		S2	134.07	0.84	0.36
18	T	M	98.72	0.70	0.35
		O	118.13	0.77	0.35
		S1	98.81	0.72	0.36
		S2	109.07	0.75	0.36
19	B	M	151.21	0.85	0.34
		O	157.38	0.84	0.32
		S1	160.79	0.85	0.33
		S2	148.18	0.89	0.36
19	M	M	124.25	0.76	0.34
		O	130.09	0.79	0.34
		S1	126.52	0.77	0.34
		S2	128.19	0.77	0.34
19	T	OM1	91.03	0.80	0.42
		OM2	112.01	0.84	0.40
		S1	106.74	0.82	0.40
		S2	108.33	0.82	0.39
20	B	OM1	228.47	0.85	0.26
		OM2	158.93	0.81	0.31
		S1	157.19	0.84	0.33
		S2	188.31	0.79	0.28
20	M	OM1	140.96	0.81	0.33
		OM2	151.99	0.84	0.33
		S1	146.07	0.83	0.34
		S2	137.44	0.85	0.36
20	T	OM1	113.78	0.74	0.35
		OM2	108.23	0.74	0.36
		S1	107.00	0.76	0.36
		S2	99.40	0.71	0.36
21	B	M	115.81	0.72	0.33
		O			
		S1	140.60	0.78	0.32
		S2	133.33	0.74	0.32
21	M	M	137.41	0.80	0.34
		O	128.19	0.80	0.35
		S1	134.23	0.79	0.34
		S2	129.93	0.75	0.33

1	2	3	4	5	6
21	T	M	122.22	0.84	0.38
		O	121.70	0.83	0.38
		S1	134.76	0.88	0.37
		S2	117.74	0.88	0.40
22	B	M	143.21	0.77	0.32
		O	141.99	0.79	0.33
		S1	142.65	0.75	0.31
		S2	151.15	0.79	0.31
22	M	OM1	128.35	0.73	0.32
		OM2	130.00	0.80	0.35
		S1	139.58	0.77	0.32
		S2	130.63	0.80	0.35
22	T	OM1	114.94	0.77	0.36
		OM2	130.68	0.78	0.34
		S1	125.15	0.77	0.34
		S2	125.17	0.80	0.35
23	B	M	156.34	0.80	0.31
		O	157.94	0.82	0.32
		S1	152.61	0.81	0.32
		S2	160.39	0.84	0.32
23	M	M	157.84	0.86	0.33
		O	144.55	0.80	0.33
		S1	145.18	0.81	0.33
		S2	166.06	0.88	0.33
23	T	M	131.71	0.82	0.35
		O	124.92	0.80	0.36
		S1	123.40	0.80	0.36
		S2	139.62	0.87	0.36
24	B	OM1	173.06	0.94	0.34
		OM2	154.33	0.83	0.33
		S1	168.88	0.91	0.34
		S2	172.33	0.91	0.34
24	M	OM1	126.56	0.95	0.42
		OM2	150.00	0.85	0.34
		S1	144.64	0.83	0.34
		S2	157.49	0.88	0.34
24	T	OM1	123.21	0.90	0.40
		OM2	132.64	0.81	0.35
		S1	139.41	0.91	0.38
		S2	120.81	0.90	0.41
25	B	OM1	82.75	0.64	0.35
		OM2	142.82	0.82	0.34
		S1	155.20	0.82	0.32
		S2	124.56	0.83	0.37

1	2	3	4	5	6
25	M	OM1	125.81	0.92	0.41
		OM2	146.38	0.84	0.34
		S1	139.46	0.84	0.35
		S2	152.17	0.90	0.36
25	T	OM1	111.30	0.78	0.37
		OM2	131.34	0.88	0.38
		S1	126.04	0.77	0.34
		S2	109.33	0.83	0.40
26	B	OM1	205.97	1.08	0.35
		OM2	165.75	0.87	0.33
		S1	175.08	0.89	0.32
		S2	165.35	0.89	0.34
26	M	OM1	138.01	0.81	0.34
		OM2	138.10	0.80	0.34
		S1	136.71	0.81	0.34
		S2	129.67	0.78	0.34
26	T	OM1	114.72	0.85	0.40
		OM2	109.15	0.96	0.46
		S1	98.63	0.76	0.38
		S2	116.85	0.86	0.40
27	B	M	137.28	0.75	0.32
		O	151.31	0.81	0.32
		S1	150.58	0.80	0.32
		S2	157.72	0.84	0.33
27	M	M	150.00	0.82	0.33
		O	136.26	0.78	0.33
		S1	139.80	0.77	0.32
		S2	140.89	0.78	0.33
27	T	OM1	122.70	0.78	0.35
		OM2	110.46	0.80	0.38
		S1	120.93	0.75	0.34
		S2	131.58	0.81	0.35
28	B	M	141.53	0.79	0.33
		O	130.97	0.75	0.33
		S1	143.90	0.82	0.34
		S2	149.30	0.84	0.34
28	M	OM1	127.45	0.79	0.35
		OM2	131.11	0.81	0.35
		S1	117.33	0.83	0.38
		S2	137.21	0.82	0.35
28	T	OM1	113.50	0.82	0.38
		OM2	108.54	0.78	0.37
		S1	107.43	0.77	0.37
		S2	115.97	0.80	0.37

1	2	3	4	5	6
29	B	OM1	125.81	0.77	0.34
		OM2	150.00	0.84	0.34
		S1	175.46	0.90	0.33
		S2	128.07	0.76	0.33
29	M	OM1	113.00	0.72	0.34
		OM2	110.78	0.74	0.35
		S1	95.34	0.77	0.40
		S2	112.06	0.79	0.37
29	T	OM1	101.85	0.78	0.39
		OM2	101.42	0.82	0.41
		S1	116.03	0.78	0.36
		S2	105.48	0.76	0.37
30	B	OM1	142.76	0.82	0.34
		OM2	141.38	0.82	0.34
		S1	147.49	0.81	0.33
		S2	146.90	0.82	0.33
30	M	OM1	136.32	0.81	0.34
		OM2	120.08	0.75	0.34
		S1	134.57	0.80	0.34
		S2	128.64	0.83	0.36
30	T	OM1	103.46	0.75	0.37
		OM2	111.02	0.76	0.36
		S1	116.35	0.80	0.37
		S2	100.20	0.82	0.41

Appedix 3. Green moisture content and final moisture content of the sample boards.

LTD

Boards No.	Green MC (%)	Final MC (%)	Boards No	Green MC (%)	Final MC (%)
1	2	3	4	5	6
1 B 3 A	159.6	10	1 T 3 A	144.9	9
3 B 1 A	163.1	6	1 T 4 B	141.1	8
7 B 4 B	177.4	6	1 T 5 A	149.2	6
9 B 2 A	173.8	15	6 T 3 B	159.2	8
9 B 2 B	173.2	12	9 T 3 A	168.4	9
10 B 1 B	149.9	6	10 T 1 B	154.6	6
10 B 3 B	161.6	11	11 T 1 A	170.6	7
14 B 2 B	182.3	6	12 T 1 A	155.6	6
3 B 1 B	167.0	6	14 T 3 A	162.8	8
5 B 5 A	157.7	16	11 T 3 B	149.9	11
5 B 5 B	154.4	6	2 T 1 A	152.4	8
5 B 6 B	177.7	6	2 T 3 B	149.3	10
11 B 2 A	180.0	8	15 T 1 B	149.7	7
11 B 3 B	133.3	12	15 T 4 A	171.5	8
11 B 4 B	135.2	15	7 T 1 A	167.2	6
13 B 3 B	161.6	11	8 T 2 B	151.9	7
14 B 4 A	160.3	17	10 T 4 A	160.1	8
1 B 5 A	144.1	6	Average	156.4	7.8
1 B 5 B	142.0	6	St. Dev.	9.2	1.4
3 B 4 B	153.0	6			
6 B 4 B	165.0	6			
7 B 2 A	173.8	7			
15 B 3 A	205.1	10			
Average	163.1	9.1			
St. Dev.	16.6	3.8			

1	2	3	4	5	6
18 B 2 A	161.0	11	16 T 3 A	165.0	6
28 B 4 A	195.4	8	19 T 1 B	155.7	6
26 B 4 A	154.0	12	25 T 2 A	174.7	9
26 B 4 B	164.3	12	25 T 3 B	151.6	13
27 B 1 A	195.0	6	26 T 2 B	145.1	12
28 B 4 A	188.1	6	26 T 4 A	163.5	8
29 B 2 A	156.1	12	29 T 2 B	139.8	9
30 B 2 B	192.3	10	30 T 1 A	170.0	8
16 B 2 B	212.8	6	30 T 4 B	161.3	8
17 B 2 A	193.3	8	29 T 1 A	146.7	6
19 B 2 B	192.7	6	30 T 1 B	172.8	7
19 B 4 A	186.5	8	30 T 2 B	138.3	6
20 B 3 A	199.3	12	17 T 3 B	172.0	13
21 B 2 B	220.4	18	18 T 1 A	165.9	6
22 B 1 A	183.1	6	18 T 2 A	186.7	6
22 B 2 B	201.6	16	20 T 2 B	191.7	10
24 B 5 A	192.5	7	23 T 2 A	180.1	11
25 B 4 A	192.8	6	23 T 4 B	168.0	6
28 B 2 B	195.0	6	28 T 1 B	168.0	7
30 B 5 A	175.7	9	Average	164.0	8.3
Average	187.6	9.3	St Dev.	14.9	2.5
St. Dev.	17.6	3.6			

CD I

Boards No.	Green Mc	Final MC	Boards No	Green MC	Final MC
1	2	3	4	5	6
2 B 1 A	166.8	12	2 T 4 A	168.4	10
4 B 1 B	158.9	11.5	5 T 1 A	147.9	9
4 B 2 B	189.9	12.5	5 T 2 B	143.9	9.5
4 B 3 A	186.8	19	5 T 3 B	145.4	14
5 B 6 A	196.0	9	13 T 3 B	154.6	10
8 B 1 B	177.5	9	5 T 3 B	162.9	15
8 B 2 A	183.5	14	6 T 2 A	166.0	11
9 B 4 A	165.0	9	8 T 3 B	169.7	13
11 B 5 B	196.8	13	9 T 2 B	164.8	14
6 B 1 A	196.0	11	9 T 4 A	178.5	12
6 B 2 A	183.3	16	10 T 1 A	182.3	11
6 B 3 A	177.3	10	10 T 2 A	173.9	14
7 B 4 A	183.0	10	4 T 3 B	187.5	24
10 B 4 A	174.6	11	5 T 1 A	177.3	12
15 B 4 A	199.9	13	5 T 2 B	164.6	16
3 B 3 A	174.1	22	8 T 4 B	171.4	11.5
9 B 5 A	195.8	13	9 T 2 B	163.2	16
12 B 4 A	199.1	14	12 T 3 B	190.5	16
13 B 1 B	193.3	14	13 T 1 A	181.8	14
13 B 3 A	170.2	18	Average	168.1	13.3
15 B 5 B	183.8	11	St.Dev.	13.5	3.4
Average	183.4	13.0			
St. Dev.	12.1	3.4			

1	2	3	4	5	6
26 B 5 A	188.6	11	18 T 4 A	204.8	11
29 B 2 B	192.6	11.5	29 T 1 B	151.6	10
17 B 1 B	242.4	11	29 T 4 A	157.7	10
17 B 3 A	204.5	22	30 T 2 A	182.0	17
17 B 5 A	239.7	12	30 T 4 A	171.1	11
21 B 3 A	184.9	13	17 T 1 A	224.8	12
21 B 3 B	179.9	19	17 T 2 B	186.8	11
30 B 2 A	206.4	14	17 T 4 B	188.9	13
24 B 2 A	227.0	12	20 T 3 A	166.2	17
28 B 3 B	170.7	12	18 T 1 B	173.1	9
30 B 1 B	195.2	12	24 T 1 A	210.1	14
30 B 4 B	151.7	11	27 T 3 A	178.8	10
16 B 1 A	181.4	9.5	28 T 2 B	204.9	24
20 B 3 B	232.1	11	21 T 2 B	168.6	15
20 B 5 A	211.3	11.5	22 T 2 B	180.6	12
21 B 4 A	209.0	12	29 T 4 B	159.0	9
24 B 4 A	159.3	17	Average	181.8	12.8
25 B 1 A	222.8	9	St. dev.	20.7	3.9
26 B 3 A	166.8	14			
28 B 5 A	196.2	12			
29 B 3 B	209.4	22			
Average	198.7	13.3			
St.Dev.	25.6	3.7			

CDII

Boards No	Green MC	Final MC	Boards No	Green MC	Final MC
1	2	3	4	5	6
3 B 2 B	168.8	9	6 T 2 B	180.8	14
3 B 3 B	157.7	12	8 T 1 A	167.2	8
3 B 5 A	172.0	6	8 T 3 A	162.2	17
7 B 2 B	169.7	9	8 T 4 A	164.8	11
9 B 4 A	185.3	15	1 T 1 B	174.4	6
10 B 3 A	164.4	15	3 T 1 A	166.5	7
12 B 3 A	184.0	19	4 T 1 B	165.1	8
1 B 2 B	174.4	9	4 T 2 A	151.9	11
2 B 1 B	192.6	10	6 T 1 B	175.5	8
9 B 4 B	172.5	10	13 T 2 A	161.5	10
10 B 2 A	169.2	15	15 T 4 B	176.1	9
14 B 2 A	172.8	7	1 T 2 A	134.7	5
15 B 2 B	151.8	6	1 T 2 B	123.9	5
2 B 2 A	153.9	5	2 T 2 B	133.9	11
2 B 3 A	119.6	7	11 T 1 B	148.6	10
5 B 2 A	162.0	18	11 T 2 A	133.9	13
5 B 2 B	145.1	14	11 T 3 A	133.7	18
8 B 1 A	172.0	14	11 T 4 A	132.8	6
9 B 4 B	168.4	12	13 T 2 B	134.6	13
11 B 4 A	152.2	13	15 T 3 A	164.1	15
13 B 2 B	136.2	8	Average	154.3	10.3
14 B 3 A	168.6	13	St. Dev.	18.1	3.8
14 B 5 A	160.5	14			
Average	164.1	11.3			
St. Dev.	16.1	3.9			

1	2	3	4	5	6
16 B 3 A	202.7	12	17 T 3 A	176.4	17
16 B 3 B	177.2	10	20 T 4 A	178.0	13
18 B 3 B	181.8	9	20 T 4 B	172.3	11
20 B 2 B	219.6	12	21 T 3 B	162.8	12
22 B 1 B	219.6	15	23 T 3 A	193.0	17
22 B 3 B	209.4	17	27 T 2 B	175.5	15
22 B 4 B	195.5	10	28 T 3 A	186.1	14
24 B 2 B	208.9	11	16 T 2 B	164.1	12
24 B 3 B	213.1	17	17 T 1 B	182.7	14
24 B 5 B	202.3	17	22 T 1 B	175.3	7
19 B 1 A	183.4	9	24 T 3 B	152.9	10
19 B 3 B	171.0	7	26 T 1 B	168.7	9
20 B 2 B	149.8	11	26 T 3 A	155.7	15
21 B 1 A	194.3	7	28 T 4 B	169.5	8
23 B 4 B	218.7	13	18 T 4 B	148.7	10
30 B 4 A	208.1	14	Average	170.8	12.3
26 B 2 A	172.9	9	St.Dev.	12.4	3.1
27 B 3 B	137.7	13			
29 B 1 B	165.5	6			
Average	191.1	11.5			
St. Dev.	24.0	3.4			

HTD

Boards No.	Green MC	Final MC	Boards No	Green MC	Final MC
1	2	3	4	5	6
1 B 2 A	156.7	10	1 T 4 A	118.8	6
1 B 4 B	143.4	9	1 T 5 B	138.3	6
2 B 3 B	133.4	11	2 T 2 A	155.4	12
2 B 4 A	122.8	14	2 T 3 A	130.9	15
2 B 6 B	150.8	14	3 T 2 B	132.6	15
3 B 1 A	154.8	7	3 T 3 B	142.4	15
3 B 1 B	180.3	14	5 T 3 A	141.3	8
3 B 4 A	161.0	10	6 T 3 A	148.8	15
5 B 4 A	144.8	10	9 T 2 A	138.7	11
7 B 3 A	141.1	7	9 T 2 B	148.0	23
8 B 2 B	146.9	14	9 T 4 B	137.3	8
8 B 4 B	183.3	16	10 T 2 B	138.0	10
9 B 1 A	160.6	17	10 T 4 B	135.4	6
9 B 1 B	175.7	9	11 T 2 B	132.9	18
9 B 5 B	163.0	17	11 T 4 B	161.5	15
10 B 2 B	132.9	7	12 T 2 A	158.7	11
12 B 1 A	155.7	9	14 T 1 B	143.7	14
12 B 1 B	158.5	17	15 T 1 A	155.5	6
12 B 3 B	162.6	14	15 T 2 A	131.3	7
13 B 4 A	150.7	12	Average	102.5	11.6
15 B 1 B	181.0	15	St.Dev.	10.9	4.8
15 B 2 A	189.1	6			
15 B 4 B	180.5	14			
Average	157.8	11.9			
St. Dev.	17.7	3.5			

1	2	3	4	5	6
16 B 1 B	145.3	9	16 T 1 A	159.1	12
17 B 2 B	173.4	13	16 T 3 B	108.7	6
17 B 4 B	169.0	11	18 T 3 A	157.0	12
17 B 5 B	166.9	13	19 T 3 B	129.9	9
18 B 4 B	166.7	15	20 T 1 A	159.8	10
19 B 3 A	139.9	10	20 T 1 B	139.2	9
19 B 4 B	184.7	11	20 T 3 B	132.3	10
20 B 5 B	160.2	16	21 T 3 A	140.4	7
21 B 1 B	175.5	15	23 T 1 A	181.7	14
22 B 3 A	164.0	18	23 T 1 B	160.3	11
24 B 1 A	184.0	13	24 T 2 B	160.2	7
24 B 1 B	165.5	15	25 T 4 B	156.3	12
24 B 3 A	99.1	20	26 T 2 A	151.2	15
24 B 4 B	152.4	14	26 T 3 B	115.1	6
24 B 6 B	169.1	15	28 T 2 A	172.5	10
25 B 3 B	159.8	15	28 T 4 A	164.8	13
25 B 4 B	166.2	17	Average	149.3	10.2
26 B 2 B	160.2	17	St. Dev.	20.1	2.8
27 B 2 B	163.6	14			
27 B 3 A	155.8	12			
28 B 3 A	138.2	11			
30 B 3 A	146.3	12			
Average	159.4	13.9			
St. Dev.	18.3	2.7			

Appendix 4. The average bow (mm) and crook (mm) measurements from 5 sample remnufactured boards.

A. BOW (mm)

Tree	Section	Methods			
		LOW	CDI	CDII	HTD
Leaning	Bottom	1	2	3	1
		1	2	1	2
		1	1	2	0
		3	0	1	1
		0	0	6	2
		1.2	1	2.6	1.2
Leaning	Top	1	2	3	1
		2	1	1	3
		0	2	3	3
		1	2	1	0
		2	2	0	1
		1.2	1.8	1.6	1.6
Straight	Bottom	2	2	1	3
		0	3	2	2
		0	1	1	1
		1	4	2	2
		2	1	0	2
		1	2.2	1.2	2
Straight	Top	1	1	2	3
		1	2	1	1
		2	1	1	1
		2	0	0	3
		1	0	0	1
		1.4	0.8	0.8	1.8

B. CROOK (mm)

Tree	Section	Methods			
		LTD	CD I	CD II	HTD
Leaning	Bottom	1	1	2	3
		0	2	5	1
		1	1	1	2
		0	0	1	0
		0	0	0	0
		0.4	0.8	1.8	1.2
Leaning	Top	1	1	2	1
		0	0	1	2
		0	0	0	2
		1	0	0	1
		0	0	0	0
		0.4	0.2	0.6	1.2
Straight	Bottom	0	0	1	2
		0	3	2	1
		0	1	1	0
		1	0	2	1
		2	0	1	0
		0.6	0.8	1.4	0.8
Straight	Top	2	2	2	4
		2	3	3	4
		0	0	1	1
		0	0	0	0
		0	0	0	0
		0.8	1	1.2	1.8